

metallurgy

metallurgy

Vol. 27 : No. 180

SEPTEMBER, 1960

Price 2/6

Heat Treatment

In salt bath furnaces, as in greenhouses, brings its rewards. The 'Cassel' Heat Treatment Service offers you the benefits of its experience in carburising, heat treatment, tempering, martempering and austempering.



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or call





"CLEAR SPACE" PNEUMATIC POWER HAMMERS for Accuracy and Reliability



20 cwt. "Clear Space" Hammer
Messrs. G. & J. Weir Ltd., Glasgow

MASSEY DESIGNS INCLUDE :-
Steam and Compressed Air
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Hammers, Friction Drop Hammers,
Double-Acting Steam and Com-
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"Clear Space" Hammers are as powerful, adaptable and easy to control as most steam hammers. They are cleaner and much more economical in running and maintenance costs. The ram is of forged alloy steel and is virtually unbreakable. The hammer will strike definite controllable single blows as well as a full range of automatic blows. Made in sizes from 2 cwt. to 2 ton falling weight.

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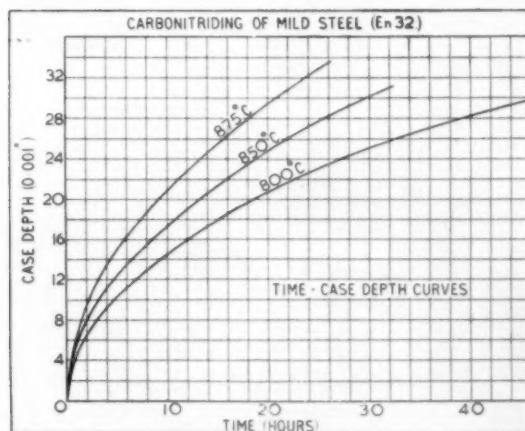
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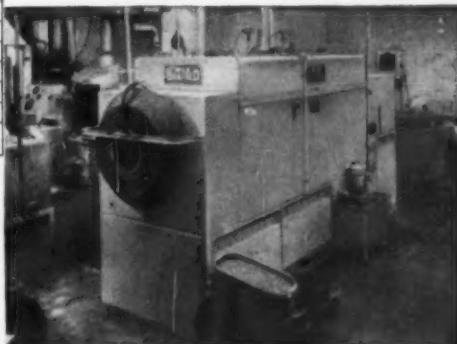
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- Atmosphere employed is raw Town's Gas and Ammonia
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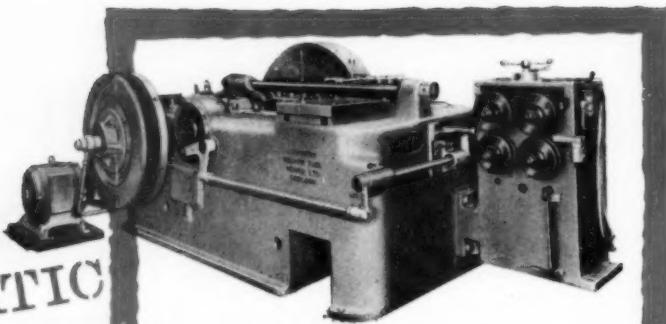
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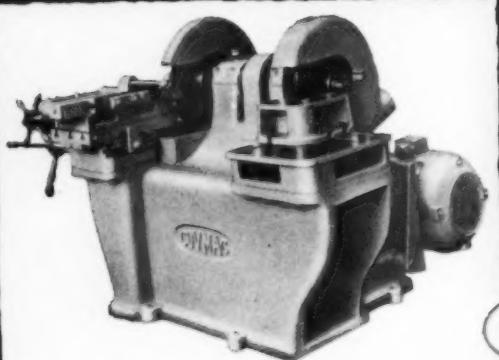
AUTOMATIC FORGER



No. 2 machine with guards removed

The stock is placed between the rolls and is then fed through the dies to the workstop. The die then closes, cutting off the stock to the required length, and delivers it to the heading position. The heading tool then completes the forging, which falls down the chute and is taken away by conveyor.

The Automatic Forger can be supplied in several sizes and for making balls of up to and including 4-in. diameter.



No. 3 machine illustrated

These machines are made in three sizes. The smallest handles bars up to 2-in. diameter. The largest size, as illustrated, takes bars up to 4-in. diameter. They are an invaluable asset to any forging or drop stamping plant.

We also make nine sizes of Standard Upsetting Machines to take bars from $\frac{1}{2}$ in. to 6 in. diameter



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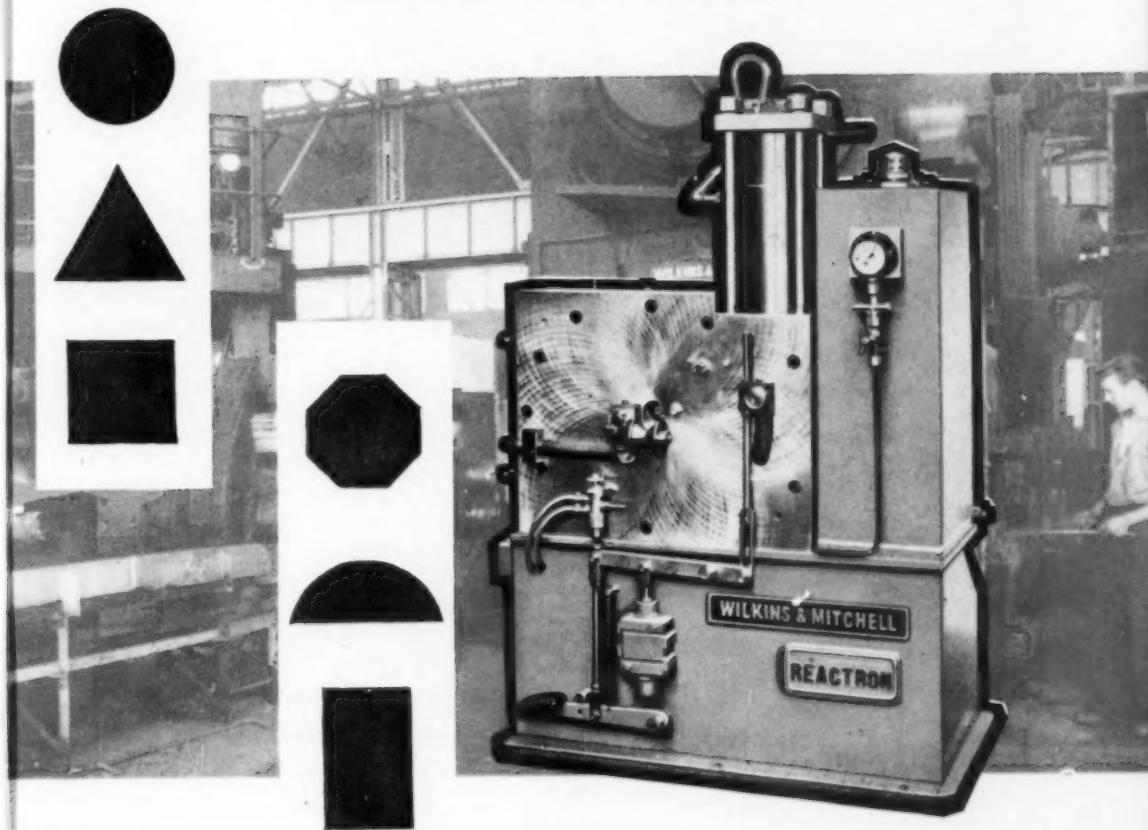
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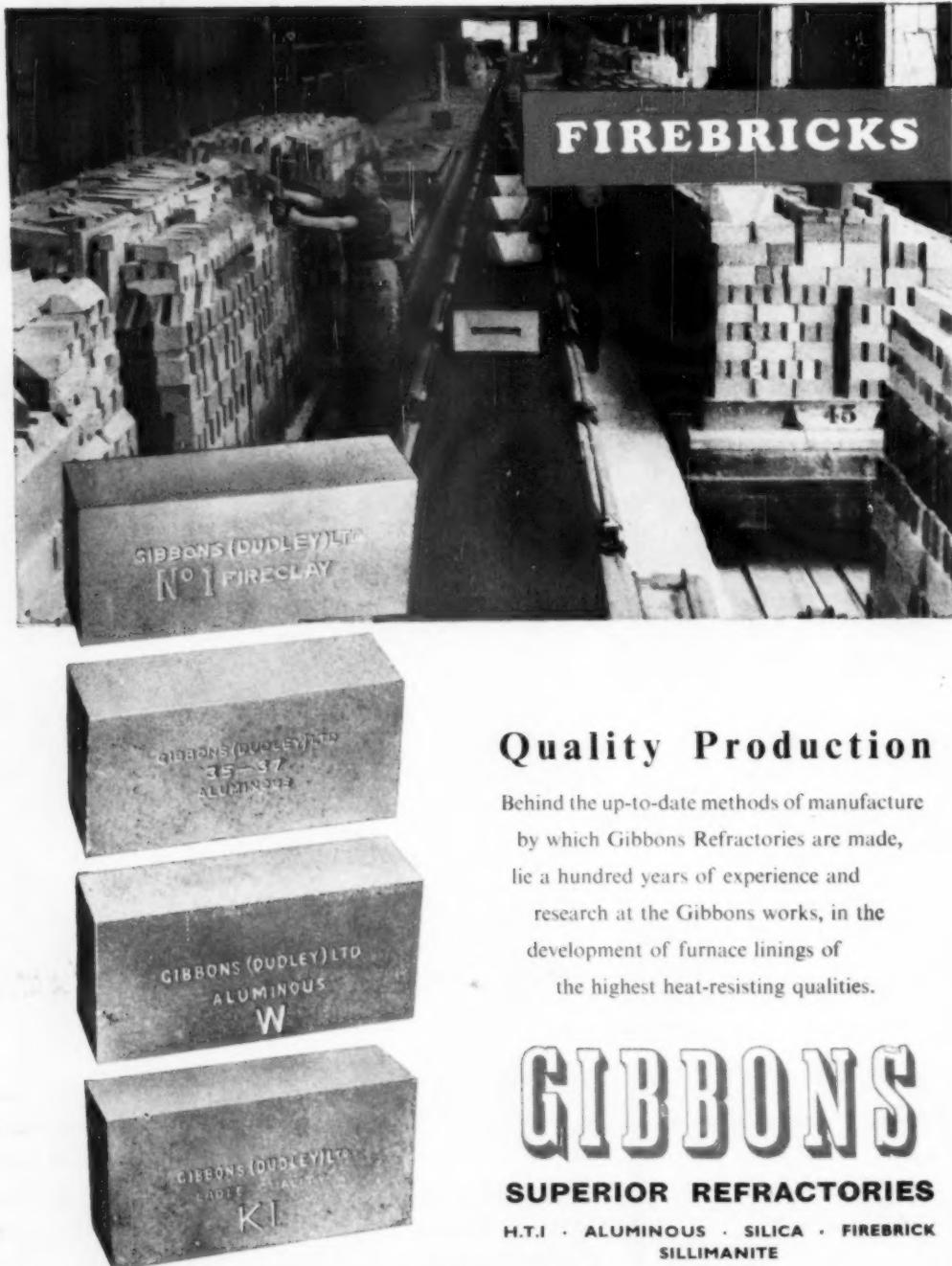
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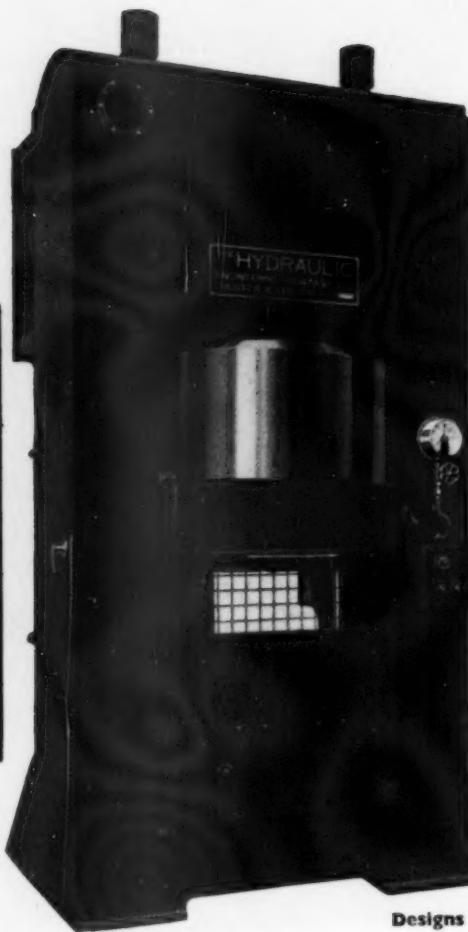
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SIZE	HEAT TREATMENT	MAXIMUM STRESS t.s.i.	ELONGATION per cent	IZOD ft. lb.
1½ in. dia.	Oil quenched 780°C.	72.0	19	69
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The benefits to be gained from the more highly alloyed case-hardening nickel steels, such as EN 33, EN 34, EN 36 and EN 39 include ease of heat-treatment, minimisation of processing distortion, and general reliability.

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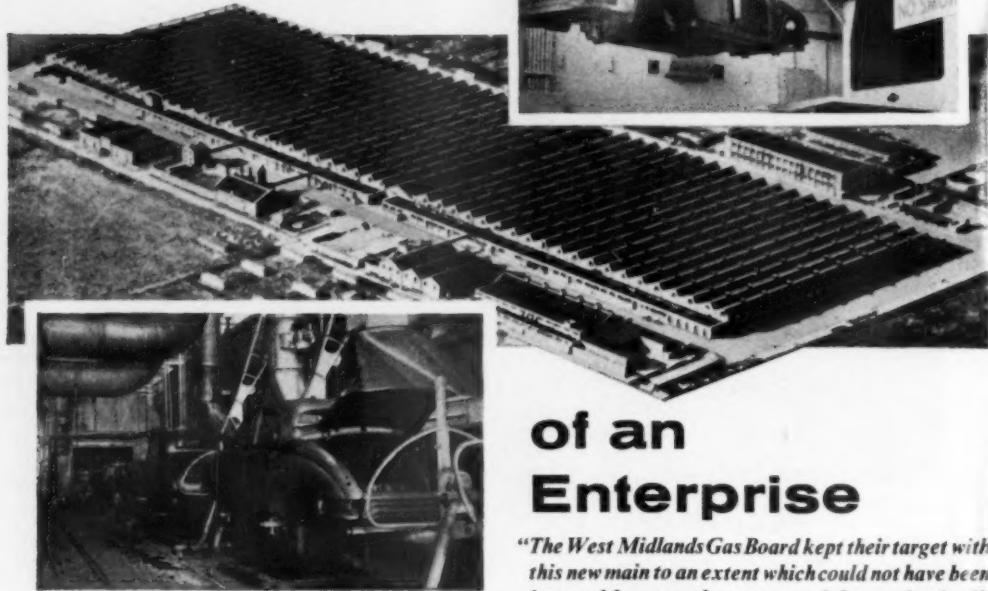


TGA 21/22

A2

Rustproofing of the Body

The Growth



The Paint Shop

The roots of the Jaguar organisation extend back for 38 years, when the present Chairman and Managing Director, Sir William Lyons, then Mr. Lyons, in company with a partner, started a modest factory for the manufacture of Swallow sidecars at Blackpool in 1922. By 1928 the Swallow Company had outgrown two factories and in that year moved to a large factory in Coventry. It was from that factory in 1931 that the first complete car made by the Company to have an identity of its own emerged under the name S.S. (Swallow Sports). In 1933 a new company was formed—S.S. Cars Ltd.—the original Swallow concern remaining in being, and in 1935 the first Jaguar saloon was introduced. Two-seater sports cars were added to the range—the Company being the first to produce a 100 m.p.h. regular series production car at a price of under £450. The War, of course, called a halt to

the progress of all motor car manufacture and in 1945 the newly named Company—Jaguar Cars Ltd.—set out with the primary object of raising the prestige of the British Car Industry abroad. It did this by combining exceptional technical design and high performance with near-perfect finish. In the years following the War, official Jaguar teams and private owners have won over 80 major international races and rallies and acquired hundreds of successes in the lesser national and international events. The fact that the Jaguar name has been blazoned across the World is confirmed by the fact that in the post-war years 56.9% of Jaguars went abroad, and no less than 48.2% captured the American market. The total number of workpeople employed in the Jaguar factory is now 4½ thousand and the Company occupies a 78-acre site in Coventry. Open competition successes have

of an Enterprise

"The West Midlands Gas Board kept their target with this new main to an extent which could not have been bettered by any other commercial organisation!"

placed the efficiency of the power and transmission systems of the Jaguar beyond reproach, but for the average motorist a high standard of finish which combines excellence in appearance with almost complete resistance to corrosion is just as important. The visitor to the factory cannot help but be impressed with the care taken on the finishing lines. A newly installed plant takes the car body on a huge spit through water rinsing, cleaning, phosphating and a chromic acid rinse. After drying, the body is dipped in a slipper paint bath to protect the innumerable nooks and crannies underneath, and then the surfacer coats are applied. Thus every car is adequately protected from corrosion. The protected bodies now pass on over-head conveyors through the remainder of the plant. The first operation is to spray sound deadener and sealing composition on the under side and

then come rubbing down, the application of the sealing coat, and the final colour coats. During the whole of this time the car body remains on its mobile spit.

The complete sequence of finishing operations is as follows:—

1. Remove any oil from body.
2. Metal preparation and fittings.
3. Apply catalyst filler to holes in the lead loaded areas.
4. Transfer body to overhead dual conveyor.
5. Clean and phosphate body in 6-station spray phosphating plant, using low temperature process.
6. Dry in dry-off oven—temperature 320 F.
7. Apply synthetic stopping as required.
8. Tac rag.
9. Slipper dip lower half of body.
10. Drain and flash off.
11. Spray primer surfacer single and double header coats using Ecco No. 30 spray gun.
12. Stove for 45 minutes at 275/280 F.
13. Unload body from conveyor on to mobile spit.
14. Spray bituminous compound for sealing and sound deadening on the underside of the car and in the engine compartment.
15. Remove sound deadener overspray.
16. Wet wipe—320 paper.
17. Spin body to remove surplus water—dry off in oven at 265 F.
18. Spray one double header coat of sealer using Ecco No. 30 spray gun.
19. Bake sealer coat 30 minutes—270/286 F.
20. Wet face sealer coat with 400 paper. Spin body to remove surplus water and sponge down.
21. Dry off in oven ten minutes at 225/230 F.
22. Vacuum clean trestle.
23. Tac rag interior surfaces and exterior.
24. Spray door shuts, engine compartment and boot interior in colour.
25. Remove overspray from exterior, solvent wipe and tac rag exterior of body complete.
26. Spray one single and one



The Final Line

- double header coat of colour.
27. Bake colour coat 45 minutes at 250/265 F.

Throughout these sequences the drying and stoving time schedules are vitally important. The gas-fired ovens used in operations 6, 12, 17, 19, 21 and 27 are held under a strict automatic temperature control by control pyrometers which instantly adjust the air and gas flow to ensure that the correct temperature is maintained.

Town gas is also employed in other parts of the plant for numerous heat treatment purposes including annealing and carburizing. These heat treatment operations are, of course, also vitally important to the ultimate performance of the gearing and transmission. The correct time/temperature schedules to introduce the necessary metallurgical structure in the metals are also achieved by control pyrometers in the furnaces, regulating the air and gas supply according to requirements.

When the recent extension of the Jaguar factory was completed it was a formidable task of re-organisation, because it was essential that production disturbances should be a minimum.

Such was the increased demand for town gas that the West Midlands Gas Board had to lay on a new high pressure gas main. Executives of the West Midlands Gas Board and Jaguar Cars collaborated closely to maintain the target they had set themselves, and those at Jaguars' commented, "The West Midlands Gas Board kept their target with this

new main to an extent which could not have been bettered by any other commercial organisation!"

Motor car manufacture is, of course, but one of the thousands of trades, professions and occupations which employ town gas in those production techniques where an automatic heat service is a paramount necessity. Each of the twelve Area Gas Boards throughout the country employs specialised industrial gas engineers, who have studied the many varied techniques of industrial gas application. Industrial gas executives from each of the Area Gas Boards meet regularly to inter-change experiences and discuss new problems which have been presented to them. The result is that any industrialist making an approach to any Industrial Officer at any Area Gas Board has presented to him immediately an overall picture of the latest techniques of heat control, based upon progress made throughout the country—and in addition, the Industrial Gas Information Bureau keeps in close touch with developments in industrial gas usage throughout the World.

*Scottish Gas Board, Edinburgh
Northern Gas Board,*

Newcastle-upon-Tyne

North Western Gas Board, Manchester

North Eastern Gas Board, Leeds

East Midlands Gas Board, Leicester

West Midlands Gas Board, Birmingham

Wales Gas Board, Cardiff

Eastern Gas Board, Watford

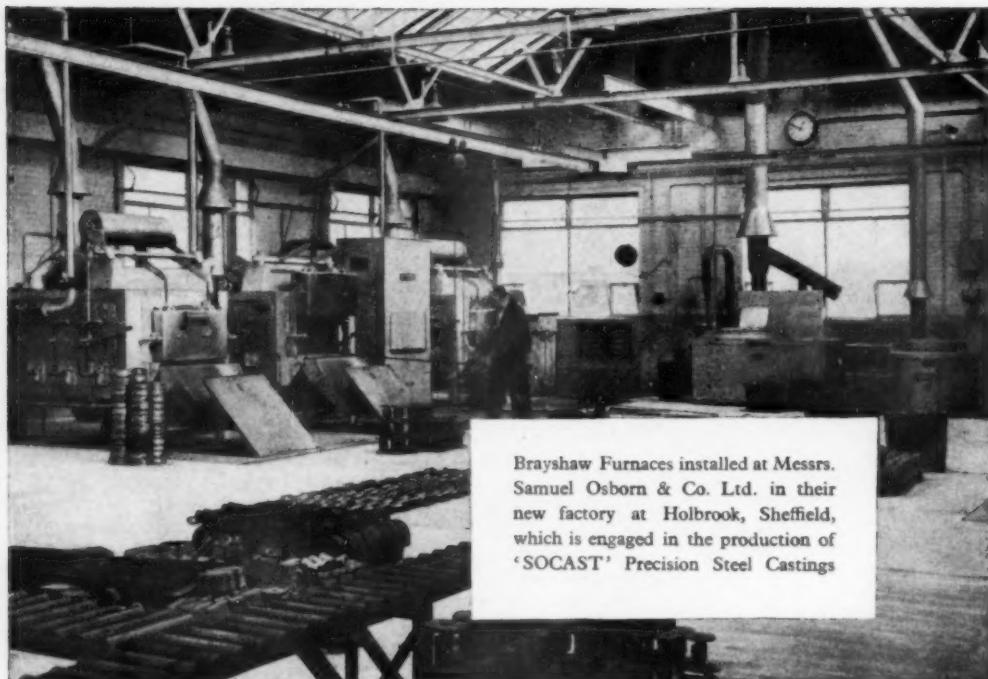
North Thames Gas Board, W.8

South Eastern Gas Board, Croydon

Southern Gas Board, Southampton

South Western Gas Board, Bath

*The Gas Council, 1 Grosvenor Place,
London, S.W.1*



Brayshaw Furnaces installed at Messrs. Samuel Osborn & Co. Ltd. in their new factory at Holbrook, Sheffield, which is engaged in the production of 'SOCAST' Precision Steel Castings

Brayshaw FURNACES For Precision Heat Treatment

Once again furnace design by Brayshaw is playing a vital part in a new industrial advance In the development of their 'SOCAST' Precision Steel Casting techniques and for the increasing production flow from their new factory Messrs. Samuel Osborn & Co. Ltd. have specified Brayshaw Furnaces. This choice demonstrates a confidence in Brayshaw design and manufacturing ability that is shared in increasing measure by forward-looking concerns the world over.

Expert consultation on new projects, re-equipment, conversion, repair and general maintenance of all types of plant is immediately available on request, please do not hesitate to

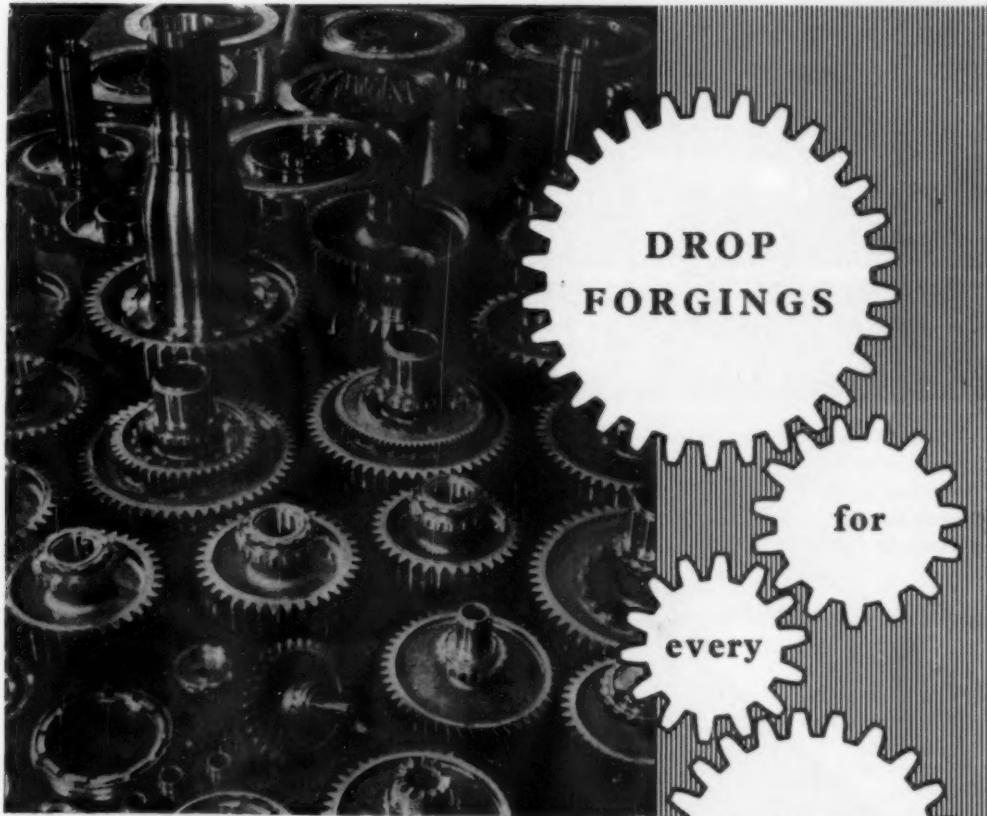
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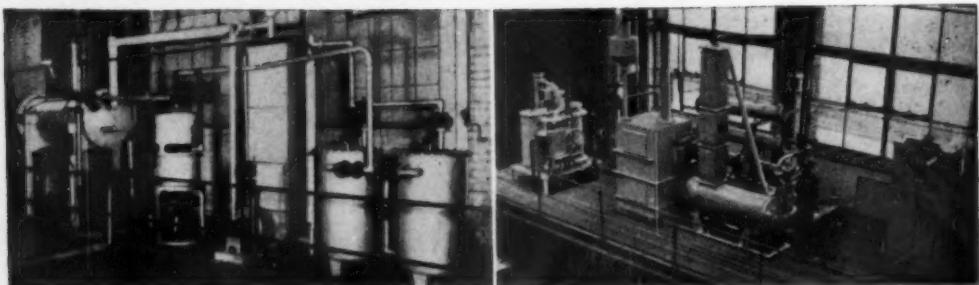
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Top left: A conventional exothermic plant, with primary and reactivated secondary drying units and equipment for removal of sulphur compounds.

Top right: A fully automatic plant for producing commercially pure nitrogen with extremely low dewpoint.

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For all forms of electric heat treatment equipment

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PRECISION HAMMER

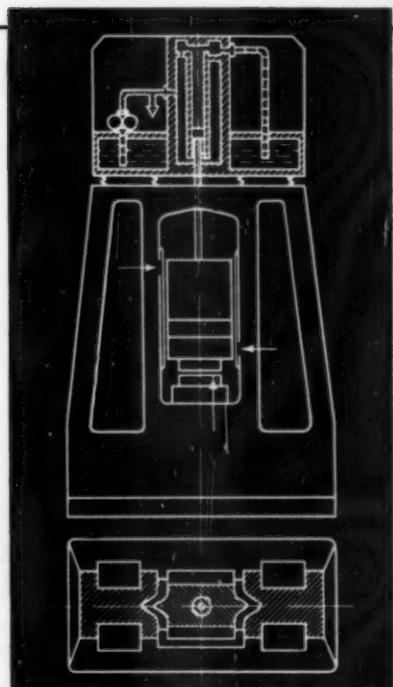
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It was developed for mass production of precision forged components and is a natural addition to the Eumuco range of chain hammers of smaller size up to approx. 10 tons.

The experience gained in double shift operation over a period of more than a year has proved that the aim in designing this hammer has been realized.



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OILHYDRAULIC ROCKER DRIVE WITH DOWNWARD PRESSURE EFFECT, high efficiency (approx. 75%) without additional cooling by water or oil. Operating medium: non-inflammable hydraulic fluid or hydraulic oil.

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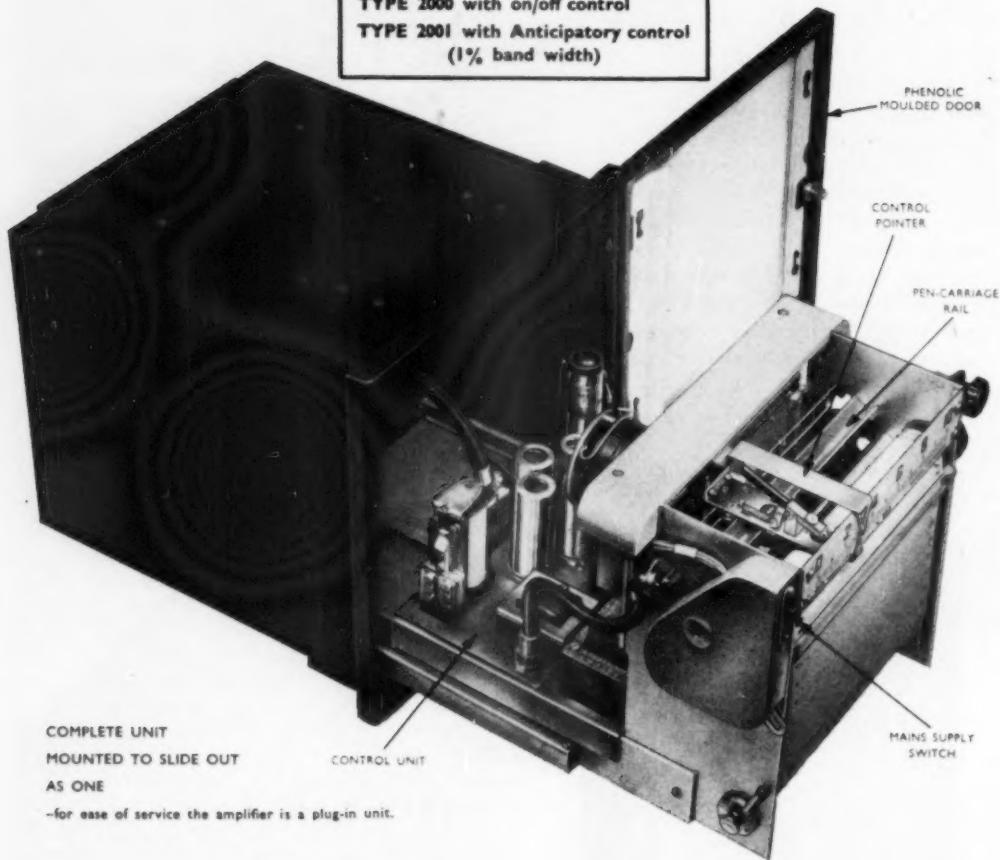
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Potentiometer Recording Controllers, SERIES 2000

TYPE 2000 with on/off control
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(1% band width)



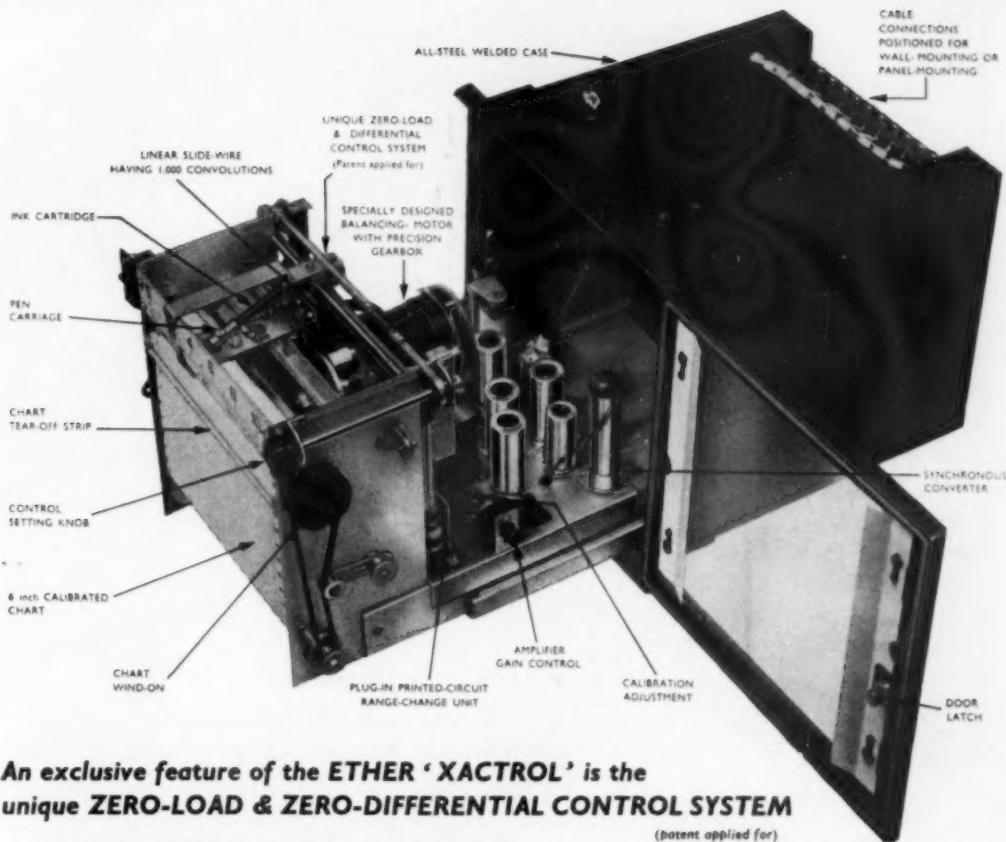
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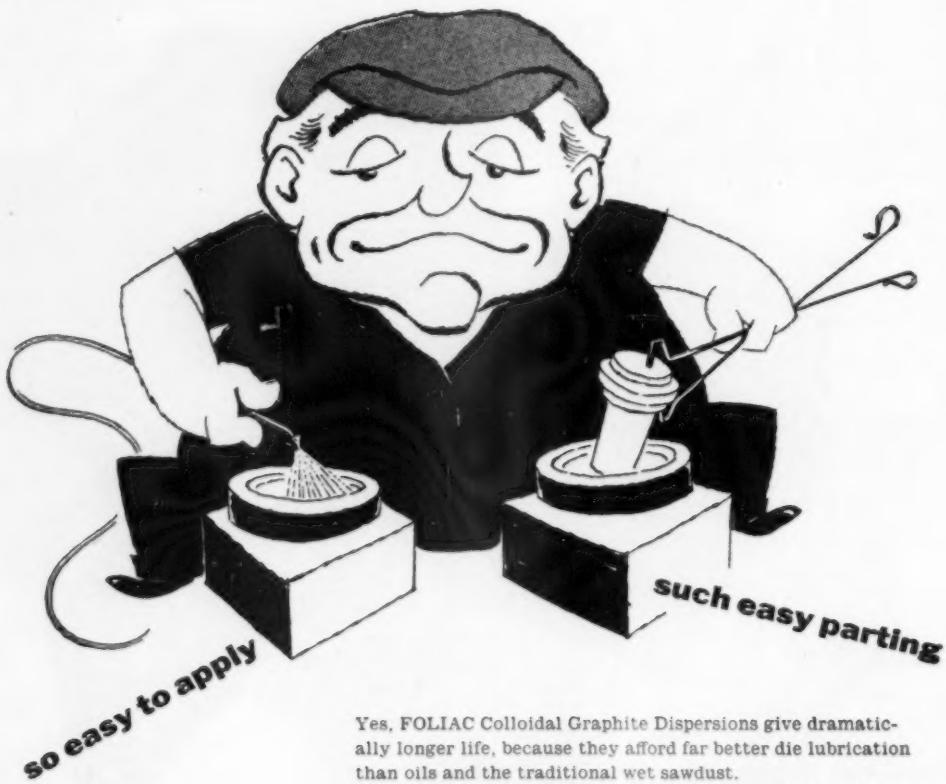
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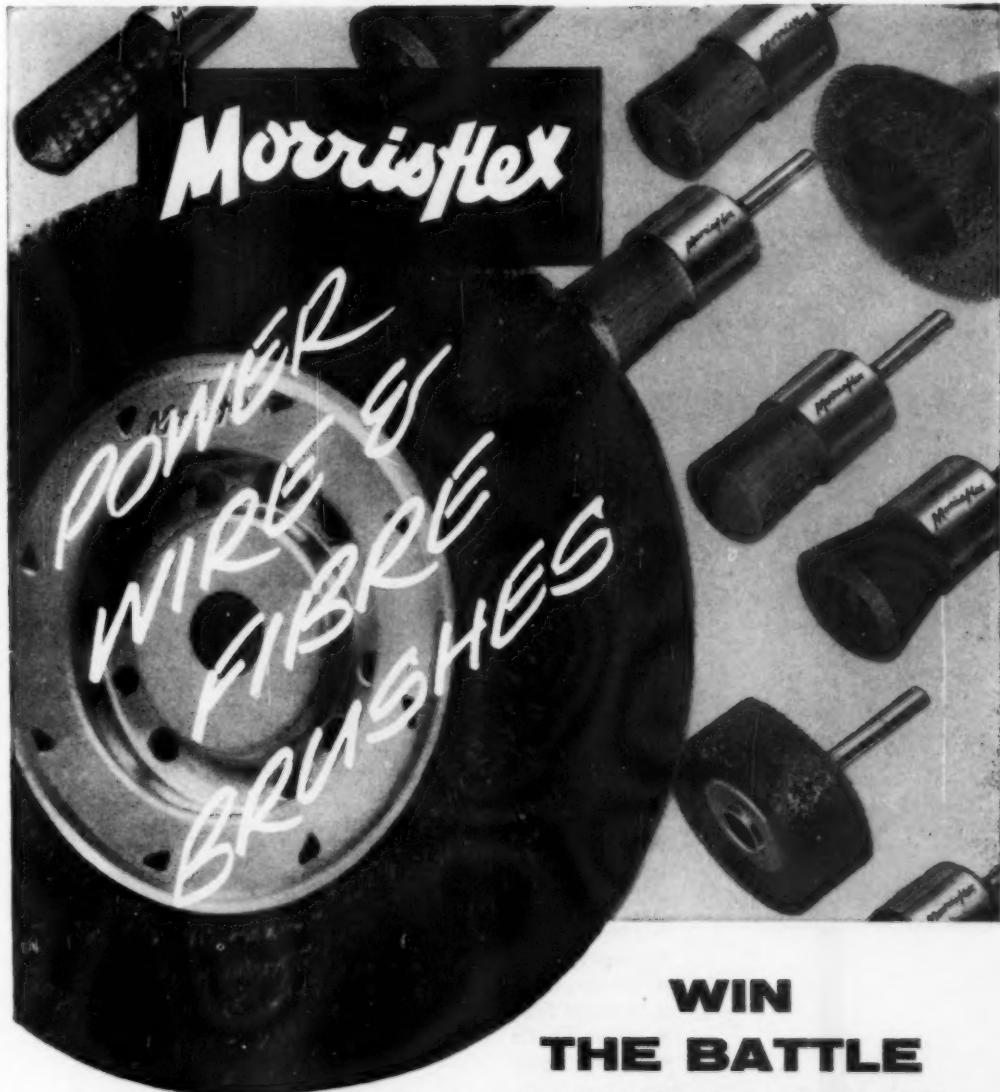
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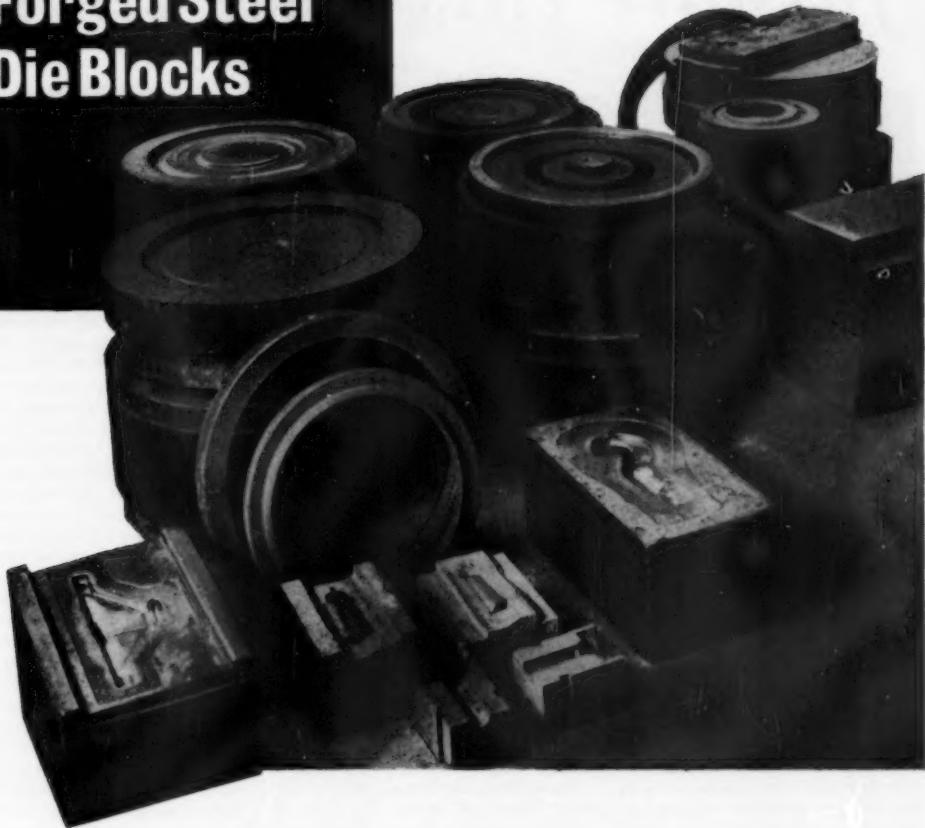
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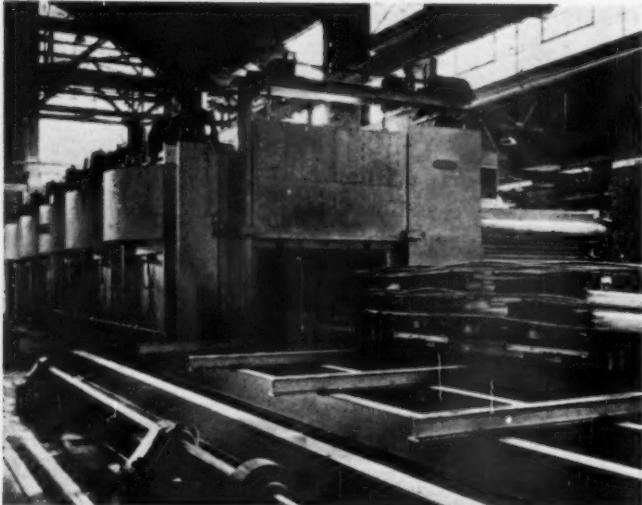
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THOS FIRTH & JOHN BROWN LIMITED SHEFFIELD · ENGLAND

G.W.B. high-rating furnace cuts cycle times



Accommodates slab lengths of 65 ft. x 6 ft. 6 ins.

In the recent large-scale development programme spread over some 30 months, the Northern Aluminium Co. Ltd. has introduced considerable quantities of new plant and handling equipment. A new batch-type furnace, designed and erected by G.W.B. at the Banbury Works of Northern Aluminium, was part of this programme. Production at Banbury, both in aluminium and a variety of aluminium alloys, embraces a wide range of sheets, discs and coils.

Owing to the occurrence of a certain amount of work-hardening (8 in. thick ingots of aluminium are hot rolled to a thickness of approximately 0.3 to 0.5 in.) it is necessary for slabs to be annealed prior to being cold rolled to

lighter gauges. The rating of this G.W.B. furnace is 1,000 kW and it comprises six independent and automatically controlled zones of equal length. Rating distribution is as follows: Zone 1 220 kW, Zones 2-5 150 kW each, Zone 6 180 kW. *Owing to the high rating, cycle times as low as 4 hours are regularly obtained.* The maximum temperature of the furnace is 600°C, normal operating temperature being rather lower than this figure.

The heating chamber is lined throughout with heat-resisting alloy, backed by a thick wall of Moler insulating bricks, thus reducing heat losses to a minimum. The furnace casing is constructed from sheet mild steel braced with steel rolled

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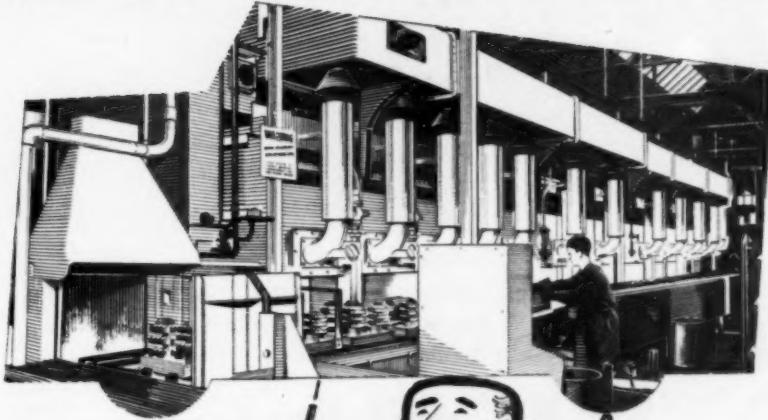
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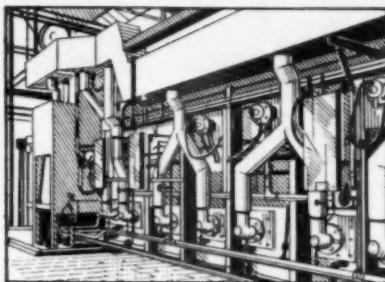
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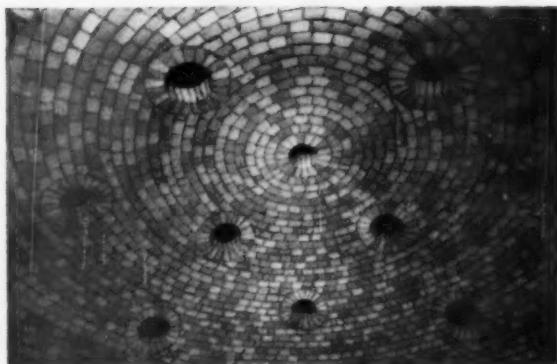
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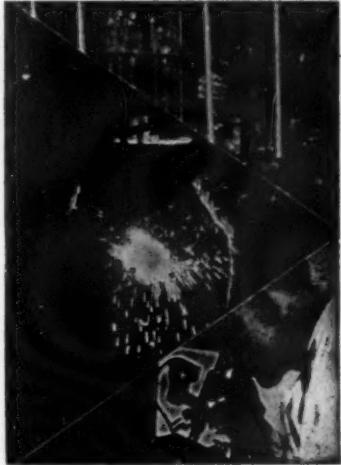
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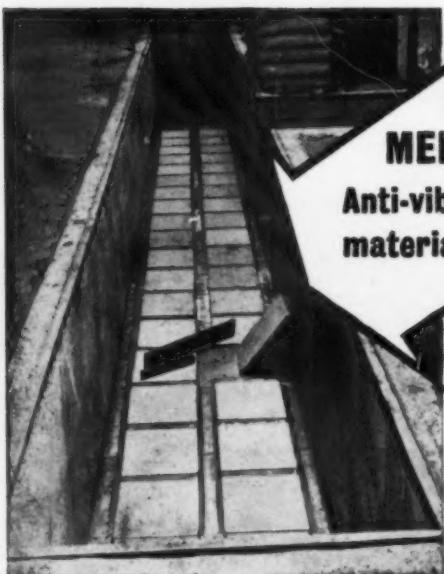
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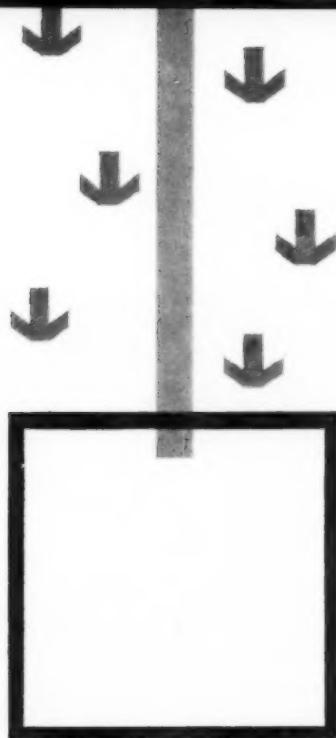
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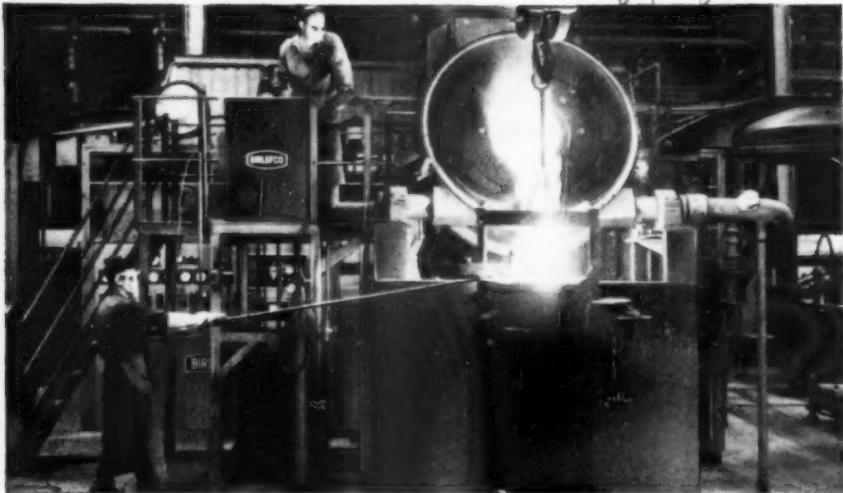
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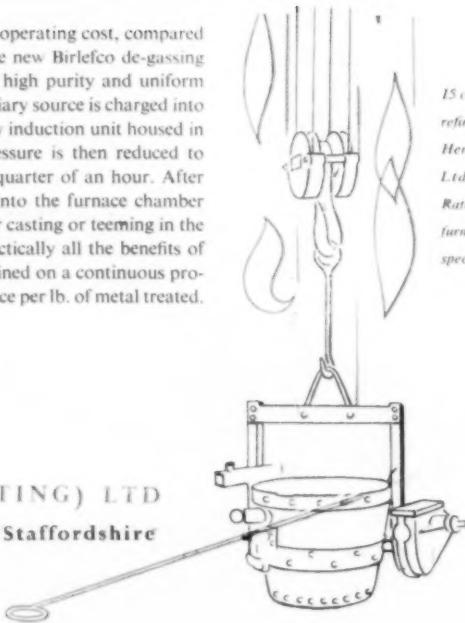
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September 1960

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Metal treatment

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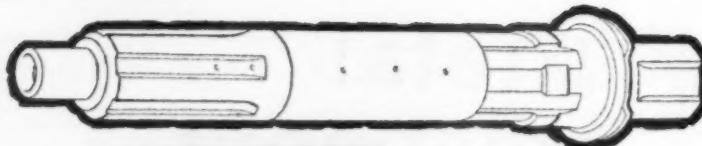
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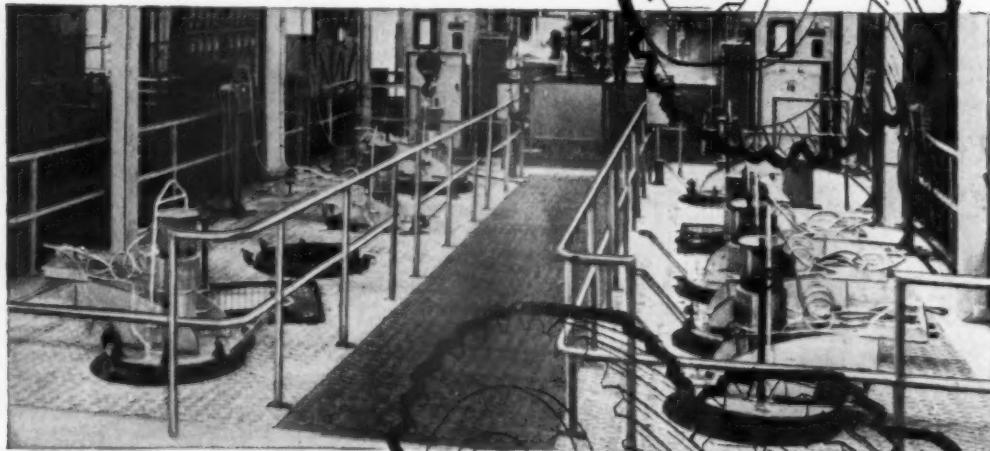
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China—the leap forward

CHINA is almost certain to become the world's third largest steel producer, after U.S.A. and U.S.S.R. within about 15 years. (*Financial Times*, August 25.) The probability of error in forecasting future trends increases rapidly with an increase in the period involved, but even conservative estimates admit a strong possibility of this prediction being realized. A recent study by the Economic Commission for Europe, 'Long-term trends of the European iron and steel industry', has also attempted to predict trend values for countries outside Europe. The figure given for China and N. Korea (unfortunately these are combined in the estimate) is 52 million tons output by 1972-75. Allowing a figure of 6 to 7 million tons for N. Korea leaves the Chinese output at about 45 to 46 million tons. This figure may be compared with the following forecasts also included in the report: U.S.A., 147.5; U.S.S.R., 117; W. Germany, 37; Japan, 36.5; and U.K., 35 (all in million tons).

As if this figure was not already sufficiently impressive, 'China Trade and Newsletter' in its June issue, criticized the E.C.E. for having made a 'distinctly low' forecast. The E.C.E. had postulated an annual average rate of growth of 16.4% from 1957, but the rate during 1953-8 was 31.7% rising to 49.5% in 1958 and 57% in 1959 with a planned target of 38% increase for 1960. According to 'China Trade', on a quite conservative estimate, China would be making nearly 40 million tons by 1965, and a quite possible figure would be 50 million tons by 1966.

Be that as it may, there are indications that many problems still have to be solved before such outputs become an actuality. Although it is sometimes assumed that the small 'backyard' plants have been swept away with the coming of the modern large-scale plants in the last few years, it still remains true that one-third of the total output depends on these small and medium-size works. Moreover, the wide distribution of coal and iron ore in the country makes the policy of small local works very attractive in view of the saving in transport costs, and China is going all out to improve the quality and quantity of output. However, this is just the difficulty—quality is undoubtedly being improved but too often apparently at the price of reduced quantity.

The major steel plants also are not exempt from troubles. The weather hazard affected production last month and Anshan, the largest steel centre, had to close down blast furnaces and open-hearts for a fortnight owing to torrential rain and floods. Another possible source of setback is an unconfirmed report of an exodus of Russian technicians who play a vital part in the modern steel plants. In any case, the Peking authorities are having to insist that every measure must be taken to catch up on the 1960 steel targets.

On the other hand, there is no doubt that the steelmaking scene in China is developing at an astonishing rate. She already has a fixed open-hearth furnace of 600 tons capacity and several blast furnaces of over 42½ cu. ft. volume. Anshan, with an annual steel output of about 5 million tons, is among the ten largest integrated plants in the world and is soon to be joined by Paotow and the giant complex of Wuhan now under construction. Research is being actively pursued in all aspects of steelmaking and has led already to such measures as the use of blast temperatures of 1,000°C for smelting. It is indeed obvious that developments taking place in the new China are likely to become of increasing concern to British steelmakers in the not-too-distant future and the steelmakers have not been slow to accept the challenge. At the suggestion of Mr. R. Sewell of the United Steel Companies Ltd., a course in Chinese is being held at the local college of technology, Sheffield, this autumn to enable research workers in the steel industry to gain the means of studying Chinese technical literature first hand. In view of the dearth of suitably qualified technical translators, this seems a matter of considerable urgency and we wish the course every success. The old Chinese writing, which is still in use for technical literature, is by no means easy to master, but we hope as many as possible will undertake what promises to be a most rewarding task.

Barrington Hooper, C.B.E.

IT is with deep regret that we record the sudden death from coronary thrombosis on September 2 of Mr. Barrington Hooper, chairman of Industrial Newspapers, Ltd., the company which he created 34 years ago and to the extension and development of which he had unremittingly devoted his undoubted genius in the publicity field.

His gifts found early recognition when, for the seven years up to 1914, he served on the staff of the Daily Mail under Lord Northcliffe, whose ability and concepts he always held in high regard. This early experience led him into a number of outstandingly successful achievements, notably the promotion of the War Bond Tank Campaign in 1916 and the subsequent Victory Loan and Food Economy campaigns. For these services he was awarded the CBE in 1920.

After a brief spell of political activity, promoting the short-lived National Party, in 1924 he was appointed Controller of Publicity for the British Empire Exhibition at Wembley, whose prospects at that time had fallen to a low ebb, and there were few recollections which gave him greater pleasure than the world-wide success which was ultimately attained for that event.

In 1926 he formed Industrial Newspapers, Ltd., in association with, among others, Mr. Harold Jeans, who later became chairman of the company with Mr. Hooper as managing director. The association continued until 1955 when, on the retirement of Mr. Jeans, Mr. Hooper also took over the chairmanship. At the time of the company's foundation its publications were relatively few, but the number grew steadily and the new approach and vigorous policy brought to bear on their publication launched a new epoch in trade and technical journalism.

Mr. Hooper, who was 75, was a man of wide interests, largely concerned with the technical and industrial fields covered by the journals he published. He had almost the unique distinction of having served as a member of Council of the Advertising Association since the foundation of that body, and he enjoyed a wide circle of friendship in political and publicity circles through his member-

ship of the Thirty Club and the Constitutional Club, of which latter he was managing trustee.

Mr. Hooper suffered a heart attack on his return in June from the Southport conference of the National Association of Colliery Managers, an organisation in which he took a most active interest. Accepting the warning of his medical advisers he spent three weeks in hospital, but was soon back at his desk, as cheerful as ever. He was, in fact, a man who enjoyed every minute of the working day.

His special organizational abilities had benefited other institutions and societies as well as the National Association of Colliery Managers. Among the many



may be mentioned the Institute of British Foundrymen, of which Mr. Hooper had been an elected member of the General Council and a member of the Finance Committee since 1939. He was also a member of the Midland Institute of Engineers and the Iron and Steel Institute, attending many of the institute's foreign meetings.

Mr. Hooper was a kindly man who liked people and liked meeting people—and in turn they liked him. He will be sadly missed by those who knew him in the many fields in which he was so active until his sudden death. A memorial service will be held at St. Bride's Church, Fleet Street, London, E.C.4, at 12.30 p.m. on September 20.

The solidification of alloys

A. KOHN and J. PHILIBERT

At the last autumn meeting of the Société Française de Métallurgie, the authors presented a contribution to the solidification of alloys subsequently published in the 'Revue de Métallurgie,' April, 1960. The following article, which is concluded in this issue, has been specially prepared by the authors to give the main conclusions of their research without entering into the detailed experimental evidence presented in their original study. The authors are with the Institut de Recherches de la Sidérurgie, France, Mr. Kohn being head of the Special Metallography Division

concluded from last month

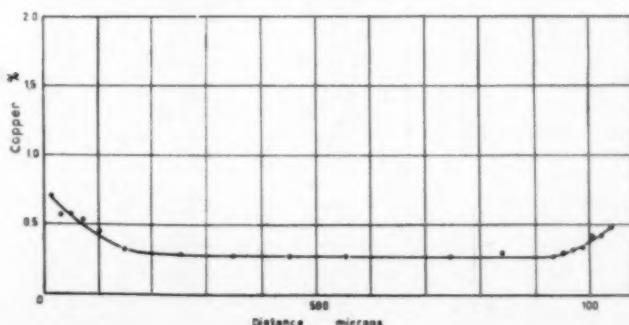
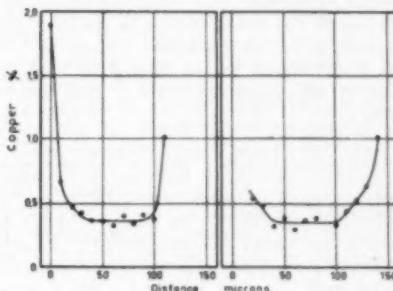
THE RESULTS OBTAINED during these numerous analyses bring into evidence the following facts:

Core of a dendrite. The copper content along the axis of a branch of dendrite is remarkably constant throughout the whole inner region of this branch. It only rises when it comes near to the limit of this branch. This characteristic, which appears clearly on the specimens which have been cooled slowly, in which the dendrite branches can have a length of at least 1 mm. (fig. 9), has also been observed on all the specimens examined, even on a specimen which was cooled very rapidly.

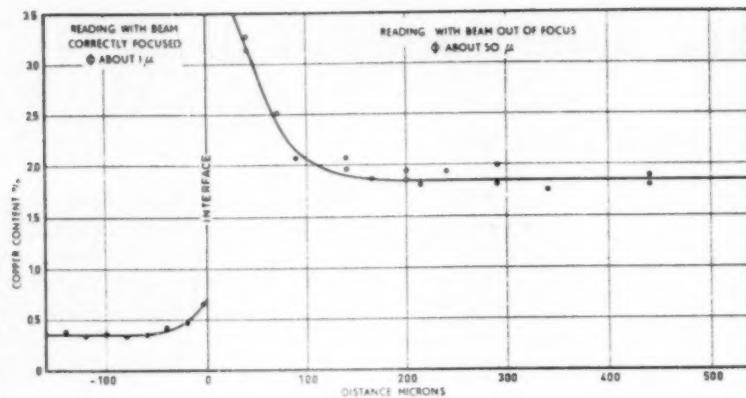
The values of the copper content of the inside portion of dendrite branches are practically the same at various points of any one crystal. This value, C , is definitely lower than the average copper content, C_o , of the specimen when examined under the microprobe (that is to say than the copper content of the molten metal which originated the dendrites being analysed). The ratio C_o/C of these two contents is between 4 and 6.

Metal liquid at moment of quenching. The various analyses, carried out with the de-focused beam, of the specimens quenched during solidification, show a very clear enrichment of the inter-dendritic spaces, the copper content in the centre of this region being always much lower than the content in the neighbourhood of the large dendrites formed before the quenching.

Measurements taken in the immediate vicinity of



9 Microprobe analysis curves, showing variation in Cu content in a dendritic branch of Al-Cu alloy with 2% Cu. LEFT Specimen cooled at 6°C./min., then quenched; ABOVE Specimen cooled at 180°C./min.



10 Microprobe analysis graph showing variation in copper content on one side and on the other side of the solid-liquid interface of a sample of Al-Cu alloy, 2% Cu, cooled at 6°C./min., then quenched during solidification

these dendrites show that the copper content, C , is 10 to 12 times as large as the copper content C_o inside the dendrite branches, but the value of the copper concentration falls regularly as it gets further away from the dendrites to reach a constant value at a distance of a few hundred microns (C_o). This value practically corresponds to the average copper content of the specimen (fig. 10).

These results confirm, then, in a direct way, that under the conditions in which solidification of the specimens examined has been carried out, the excess copper has not been able to spread itself in a homogeneous way through the liquid metal but that it has accumulated in the neighbourhood of the surface of the dendrites during their period of growth.

VARIOUS FERROUS ALLOYS

In the course of various earlier studies^{9, 11} analyses were made of the dendritic structure of ferrous alloys or of samples of steel of industrial quality.

The results show the same general features: whatever the element being analysed (molybdenum, chromium, nickel, manganese, phosphorus, arsenic, silicon) its concentration inside the dendritic branches remains constant over length contained within from 25 to 60% of the distance separating the middle of two inter-dendritic spaces. The figurative curves, concentration-distance, therefore show a level line bounded by concentration 'peaks,' which correspond to the middle of the inter-dendritic spaces. The table gives some of the values obtained.

Type of alloy	Mean C content of sample	Element analysed by microprobe	Mean content C_o of element analysed	Concentration C in body of dendrites	Concentration C' in middle of inter-dendritic spaces	Ratio C/C_o
Fe-As ⁹	—	As	0.15	0.13	0.16	0.85
Fe-As-C ⁹	0.32	As	0.29	0.15	6.3	0.5
Fe-P	—	P	1.10	0.65	eutectic (0.36)	0.6
Fe-P-C ¹¹	0.45	P	0.032	—	eutectic	—
Fe-P-C	1.0	P	0.77	0.20	eutectic	0.4
Fe-P-C	0.88	P	1.35	0.25—0.30	eutectic	0.2
Fe-Mn-C ⁹	0.62	Mn	0.51	0.47	0.75	0.97
Fe-Cr-C ⁹	0.47	Cr	0.50	0.43	1.65	0.86
Fe-Ni-C ⁹	0.46	Ni	1.48	1.35—1.40	1.4—1.45	0.93
Fe-Mn-Mo-C	0.36	Mo	0.50	0.46	3.1	0.92
Fe-Mn-Mo-C ⁹	0.36	Mn	~1.30	1.30	2.1	—
Steel rich in As (100 kg. ingot) ¹⁰	0.41	As	~0.91	0.085	1.6	—
Samples taken from 100-ton ingot of Ni-Cr-Mo alloy steel ¹¹	0.35	P	0.022	—	0.090	—
	0.35	Ni	2.5	2.4	3.25	0.96
	0.35	Cr	0.66	0.55	(1.05)	0.83
	0.35	Mo	0.29	0.13	0.95	0.45
	0.35	Mn	~0.50	0.50	0.20	—

Interpretation of results

MECHANISM OF SOLIDIFICATION

On the basis of all the previous observations, it is possible to describe the process of solidification of aluminium-copper alloys as follows:

When the metal is cooled, nucleation takes place at a temperature which is a few degrees lower than the temperature of a crystal in equilibrium with a liquid having the concentration of the alloy (supercooling phenomenon). The nuclei have a lower copper concentration than that of the liquid from which they are generated, and throw off around themselves the excess of copper. Copper enrichment of the liquid phase at the solid-liquid interface, increases as the nuclei are growing and this increases the copper content of the outer part of the growing crystal. (Fig. 11.) This simultaneous increase in the copper content of solid and liquid phases, on either side of the interface, continues until a practically steady state is established under the double effect of the branching formation of dendrites (which increases the ratio of the surface of each crystal to its volume) and of diffusion (which disperses through a greater volume of liquid the copper thrown off by the crystal growth). It is thought that this quasi-steady state is reached very shortly after nucleation.

At the same time, the latent heat produced reheats the whole of the alloy, the mean temperature of which rises. Examination of the recorded curves and of the thermal characteristics of the alloy shows that the maximum temperature is attained at the end of a period of time corresponding to solidification of about 1% of the total mass of the alloy,

that is to say when the mean diameter of the crystals is about one-fifth of the diameter reached on complete solidification (for example, 1 mm. for crystals whose final size will be 5 mm.).

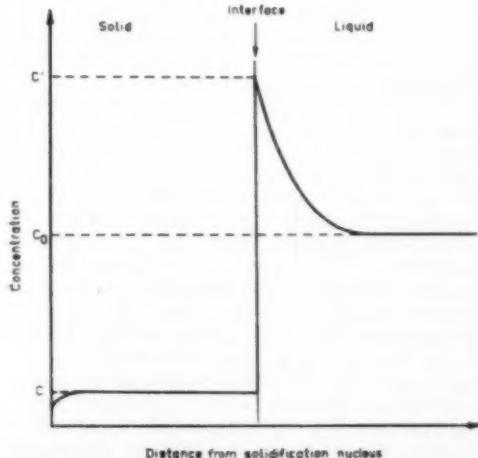
It may be thought that, at this moment, the quasi-steady state of growth has already been established. The temperature of the alloy is the equilibrium temperature of crystals with concentration C with a liquid of concentration C about 10 times higher. (Fig. 11.) Owing to the existence of this quasi-steady state, the temperature remains practically constant. This temperature can be taken as the liquidus temperature of the alloy with original concentration C_0 , if it is agreed to designate thus the temperature which the solidification of the metal begins when it is cooled slowly, but our observations show that it is not the temperature of a liquid having a concentration C_0 in equilibrium with the corresponding solid.

The dendrites thus grow at a practically constant temperature until they have become very close to one another. Then solidification enters the transitory period during the course of which the copper content of the liquid increases progressively. Towards the end of this period the alloy is composed of dendrites having a practically constant chemical composition, except in their outer parts, and of liquid much enriched in copper. Solidification then goes on over a range of temperature of 100°, during the course of which the greatest part of the heat liberated outside by the alloy will be due to the cooling down.

SOLIDIFICATION OF STEEL INGOTS

The results of analyses made with the Castaing microprobe on ferrous alloys are similar to those obtained during investigations of aluminium-copper alloys and this justifies an extension of the interpretation, previously given to steels. From the above observations on nucleation, an attempt can be made to state the conditions of formation of different crystallization zones inside killed steel ingots, which have, indeed, already been described.¹²

As has been stated in the introduction to this Paper, any valid explanation of the process of solidification must take into account that this phenomenon begins by the formation of nuclei at a temperature which is below the liquidus temperature of the alloy in question, a fact which had been unknown in early explanations and which has been neglected in interpretations given more recently. For a given industrial metal, these nuclei are generated at a temperature which depends upon various factors still very little known: crystallographic properties of the embryos, rate of cooling, local enrichment of the alloyed element in the metal and also, perhaps, energy communicated to the liquid by shocks or vibrations as many recent



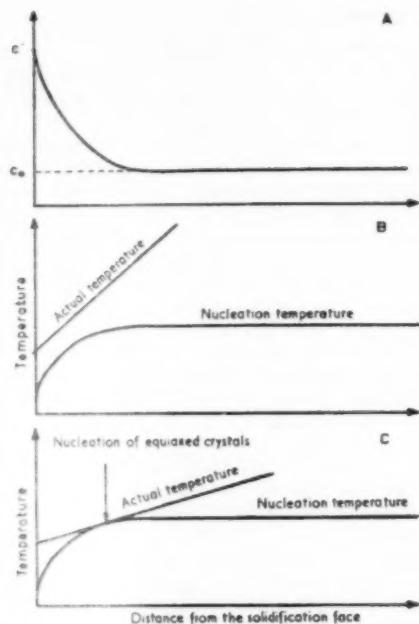
11 Variation in alloying element content in a crystal during growth and in the liquid which surrounds it

investigations have shown. Thus, the essential factor which has to be taken into account is not the liquidus temperature of the alloy (this temperature is only related to the conditions of growth of the crystals already formed) but what may be called its 'nucleation temperature.'

Skin zone. When the molten metal comes into contact with the wall of the ingot-mould it is cooled very rapidly and the formation of the first nuclei does not release sufficient heat to allow the temperature rise immediately. As the temperature continues to fall, a large number of solid impurities, present in the metal, act as embryos, whereas they would have remained without effect if the thermo-dynamic disequilibrium of the alloy had not been so high. The very numerous crystals which are thus generated inside the metal which is heavily supercooled, are not able to grow to a large size, and a very fine grain structure will be obtained characteristic of this outer zone of the ingot.

Basaltic zone. Owing to the heat released by the formation of these crystals and the heat transmitted by conduction from the inner part of the ingot, this zone heats up again and there comes a moment when the liquid metal situated in the inner part arrives at a temperature lying between the nucleation temperature and the liquidus temperature. New nuclei can no longer be formed but the crystals already formed can grow towards the centre line of the ingot, the only direction in which their development is not hindered by their mutual growth. Moreover, as many investigators have noted, dendritic growth is characterized by a more rapid development along certain crystallographic directions ($<100>$ axis in the case of cubic crystals). Amongst the many small dendritic crystals which have begun to form on the inside limit of the skin zone, some of them happen to have a preferential orientation practically parallel to the direction of the thermal gradient. These crystals are going to develop more rapidly than neighbouring crystals having a less favourable orientation, and then, subsequently, they will prevent the growth of these latter ones. It is in this way that elongated crystals having a common crystallographic direction are formed in the so-called basaltic zone. These crystals, whose transversal growth is limited by their mutual presence, can, on the contrary, grow in length in the direction of the temperature gradient so long as new crystals cannot be nucleated in front of the actual solidification interface.

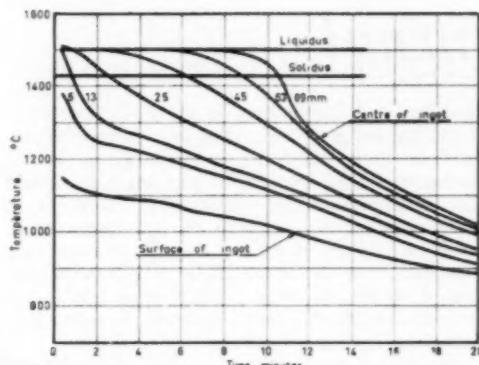
Equiaxed zone. A little more precise description must be given of the variation in concentration of the liquid in the neighbourhood of a growing basaltic crystal. (Fig. 12A, which corresponds to the diagram on Fig. 11.) To each concentration value there corresponds a definite nucleation



12 Changeover from basaltic to equiaxial crystallization. The curve of nucleation temperature ahead of the basaltic crystal solidifications depends upon the concentration of alloying element (A) following the magnitude of the gradient temperature, nucleation cannot take place in front of this liquid (B) and basaltic crystallization continues or equiaxed crystals are formed (C)

temperature. So long as the temperature gradient in the liquid is high there is no point of this phase which is at a temperature equal to or lower than the nucleation temperature. (Fig. 12B.) Growth of the basaltic crystals continues.

The superheat in the ingot core is progressively evacuated by conduction through the already solidified crust of the ingot and the temperature gradient in the liquid metal is lowered. There comes a moment when, at one point in the liquid, situated at a distance from this interface, the temperature becomes equal to the nucleation temperature. This means that the curve representing the temperature distribution in the liquid has become tangential to the curve of nucleation temperature. (Fig. 12C.) New crystals can now be generated at that point and the basaltic crystallization gives way to equiaxed crystallization. As the temperature continues to fall in the inside of the ingot, all this zone soon finds itself at a temperature equal to the nucleation temperature. Numerous crystals now form originating from all the nuclei present in the liquid metal. All these crystals will



13 Cooling curves at various distances from the surface of a 180 kg. ingot of a 0.56% carbon steel, cast in mould (according to Bishop, Brandt and Pellini¹⁷)

grow simultaneously but with kinetics depending upon the local conditions of concentration and temperature.

As a matter of fact, the cooling curves obtained by various workers, who have put thermo-electric couples in the heart of an ingot mould filled with a liquid alloy,¹³⁻¹⁹ show that, in the inside area, the metal, after having cooled down to a temperature corresponding to the liquidus temperature, remains for some time at that temperature. (Fig. 13.) These curves have a shape exactly similar to that which was observed during solidification of 2 kg. of aluminium-copper alloy (fig. 5), in which nucleation clearly showed by the characteristic supercooling dip and it may be thought that, in that case also, nucleation took place at the moment when the temperature stopped going down. The absence of a supercooling dip on these curves can be explained by the low thermal conductivity of the protective sheath of the couples. Furthermore, the temperature was not continuously measured because multi-channel records were used and the industrial alloys studied may have had a slight undercooling. Otherwise it would be difficult to understand why the temperature could remain constant in a liquid mass surrounded by a zone in which there is a temperature gradient, without a physical transformation taking place.

Consequently, it appears reasonable that the solidification of a metal begins at a given point of the liquid bulk as soon as the temperature at this point has reached the degree of undercooling necessary to allow nucleation starting from the embryos (impurities or intentionally inoculated elements) existing in the liquid. If the metal is a low alloy, the growth of these crystals takes place over a long period at a practically constant temperature, the kinetics of this growth depending on the

local conditions by which the latent heat of solidification is evolved. When the crystals having a practically homogeneous chemical composition come close together, the metal will undergo rapid cooling during which solidification of the residual liquid strongly enriched with the alloying elements will take place. In most cases it will not be possible to say at what average temperature this will be done.

Acknowledgments

The authors wish to express their gratitude to Mme. Bizouard, engineer at IRSID, who carried out a large proportion of the microprobe analyses.

They also wish to thank Messrs. Plateau and Urbain, engineers with IRSID, with whom they have had fruitful discussions enabling them to give a precise interpretation of the phenomena observed during these investigations.

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Russian forging journal

Abstracts from the Russian forging journal — Kuznechno-Shtampovochnoe Proizvodstvo, February, 1960, 2. This is the second year of this journal devoted specifically to forging. We shall try to give indications of the contents of future numbers in METAL TREATMENT each month.

The effect of the initial grain size of an alloy of the type EI437B on the final grain size produced after mechanical working and recrystallization. M. YA. DZUGUTOV and B. F. BAKHTANOV. Pp. 1-4.

The introduction of knurling of pinion teeth into mass production. V. V. POLOVNIKOV and E. V. KUSH. Pp. 4-8.

Machines for hot and cold knurling of pinions of 198.5-412 mm. dia. with a modulus of 4-6.5 mm. in use at the Krasnii Metallist works in Konotopsk are described.

Optimum stress conditions and radii of curvature of forgings in the stamping of axi-symmetrical components. A. E. ZHURAVLEV. Pp. 9-10.

The method elaborated for calculating these conditions makes it possible to establish identical stress conditions for the working of the dies and produce comparable results for investigation of their working life.

Surface quality of press components. V. G. KONONENKO. Pp. 11-13. Surface quality of various ferrous and non-ferrous alloys as pressings has been investigated in relation to nine different lubricants, various billet thicknesses, rate of delivery of the tool, gap between pressure roller and mandrel, and the cleanliness of the machining, and dimensions of the working edges, of the tool.

An automatic press with oscillating ram. S. M. NESVIT, G. M. RODOV and I. M. PODRABINNIK. Pp. 13-15.

A full description is given of the A 863 strip blanking press with following parameters. Nominal press force 25 tons; controlled stroke of ram 5-75 mm.; strokes of ram per minute 200-500; width of strip 180 mm.; controlled pace of delivery of strip 10-150 mm.; distance between guide columns of the ram into the gap, left to right 485 mm., back to front 255 mm. Capacity of 3-speed drive motor, 7/9/10 kVA.

The use of viscose fuel oils for heating industrial furnaces. B. N. ELTYSHEV. Pp. 16-20.

Forging shops of engineering construction works are normally equipped with small or medium sized furnaces, fired by fuel oil. When viscose oils are used, inadequate filtration and preparation of the oil is a common cause of poor combustion. A special study has been made of the relative size and

quantity, and distribution, of the fuel oil droplets streaming out of the burners at various temperature and pressures, and a nomogram is given for the determination of viscosity at various temperatures and other operational parameters. A series of recommendations are given for the preparation, transport and distribution of fuel oil, and optimum conditions for the combustion of oils with viscosities of 80 and 100 E., which yield a saving in fuel oil of 10-15% and improve furnace performance.

Design and construction of specialized forging and stamping shops. An Assessment. I. P. POSPELOV. Pp. 22-25.

The Chevrolet and Dodge Forging Works in the U.S.A. (Author's impressions). V. A. MASSEN. Pp. 25-30.

Bending of rectangular section tubes without buckling or straightening. M. F. EMEL'YANOV. Pp. 31-33.

The dies for the bending operations are described in detail. Bending angles up to 200° are attained in any number of operations.

A scoop ejector mechanism for modern presses. V. YA. ANTROPOV.

A single column crank press with multi-stage blanking die for manufacturing the body of a window fastener. S. L. ZLOTNIKOV. Pp. 34-36.

The article describes the production of fasteners on a 6-stage press.

A blanking die for segment dowel billets. O. V. KUKHTAROV. P. 36.

Mechanization of the withdrawal of components by means of compressed air during cold stamping. L. S. SAGATELYAN and L. M. TSIRIK. Pp. 37-39.

Improving the technical processes of forging production. F. SH. RABANEEV. Pp. 39-40.

Combining dies with wedging devices. R. N. ZUEV. Pp. 40-42.

An induction load cell for measuring small movements. V. S. SOKOLOV. P. 42.

Industrial training in operational research

The British Iron and Steel Research Association announces the introduction of a graduate apprenticeship scheme for specialized training in operational research.

The purpose of the scheme is to train recruits not only in the specialist techniques, but also in the practical art of applying these methods to actual industrial problems.

Training will consist of day-to-day experience as a member of a team engaged on actual problems in the steel industry, followed by a more formal course in techniques, arranged in collaboration with the London School of Economics. The two-year course will culminate in an examination for the Diploma in Operational Research recently instituted by the London School of Economics.

Gas-fired heat-treatment furnaces

New techniques in the application of gas as an industrial fuel are being evolved and a planned approach to the exploitation of gas in industry is receiving much attention. At the Annual General Meeting of the Institution of Gas Engineers at Edinburgh last June, Mr. A. Higgs, M.Inst.Gas E., M.Inst.F., and Mr. R. W. Deans, B.Sc., Assoc.M.Inst.Gas E., both of the Scottish Gas Board, gave a paper covering the field of process load. The present article gives a summary of the part of their paper dealing with the contribution of the furnace-manufacturing industry to the use of gas fuel

THE WHOLEHEARTED co-operation and interest of the furnace-manufacturing industry has contributed substantially to the development of the industrial gas load in all areas. Many new techniques have been developed, and incorporated, in gas-fired plant. The increased use of insulating refractory in the construction of large heat-treatment plant, of improved multiple-burner systems and air/gas ratio control are more and more becoming standard features, materially assisting the development and retention of load.

The following installations are representative of modern plant being installed by furnace manufacturers in the Scottish Gas Board's Area.

William Beardmore & Co. Ltd.

Beardmore & Co. Ltd., of Parkhead, Glasgow, well-known manufacturers of large steel forgings and steel castings for the shipbuilding, steel and heavy engineering industries, is the Board's largest gas consumer, taking at the moment approximately 1,000 mill. cu. ft. annum of gas.

With the increased demand for precision heat treatment, to condition large forgings for the more onerous duties to which they are subjected, new gas-fired plant is continuously being installed. The heat treatment of forgings, of up to 100 tons in weight, is a complex one calling for extreme uniformity in temperature distribution, often with a permissible tolerance of only $\pm 2\frac{1}{2}^{\circ}\text{C}$. throughout the load. The ready facility with which town gas can be applied in accurately controlled quantities simultaneously by means of multiple burners enables these exacting requirements to be met.

This is perhaps well illustrated on two new bogie hearth furnaces built by Priest Furnaces Ltd., of Middlesbrough. These furnaces have internal dimensions of 50 ft. deep \times 12 ft. wide across the bogie \times 10 ft. high, and 30 ft. deep \times 10 ft. wide

across the bogie \times 10 ft. high respectively. Fig. 1 illustrates the larger of the two furnaces.

Multiple burners are fitted at high and low level, at relatively close centres, to afford the requisite heat input with independent control of top and bottom temperature. Variations in heat demand, occasioned by load, in a vertical direction, can, therefore, be compensated. The burners employed are of two types; nozzle-mixing converging-tunnel horizontal-firing burners located at bogie top level, directing streams of high-velocity combustion products across the top of the bogie and under the load; and vertical burners of the luminous-flame type giving slow combustion and long flame travel and firing upwards adjacent to the side walls. Control of temperature longitudinally is achieved in the large furnace by dividing it into three zones, and, in the small furnace, into two zones. The burner systems in these respective zones are manifolded separately to afford independent top and bottom temperature control. Honeywell Brown automatic temperature controllers are employed to control the gas/air input to these separately manifolded burner assemblies. Insulating refractory is used in all positions not subject to abrasion (that is, in the side walls and in the arches, back walls and doors), so that the general furnace structures have a low thermal capacity and are hence extremely responsive to changes in thermal input. A 'pressure' at hearth level, to prevent air infiltration, is maintained by a Honeywell Brown automatic pressure controller operating a 30-in. flue damper and sampling from multiple points located in the side walls at hearth level.

The maximum gas consumption of the larger Priest furnace is 50,000 cu. ft./h., and the furnace is capable of bringing a 150-ton load from cold to 950°C . in 12 h. The rating of the smaller unit is 30,000 cu. ft./h., with the ability to raise a 75-ton

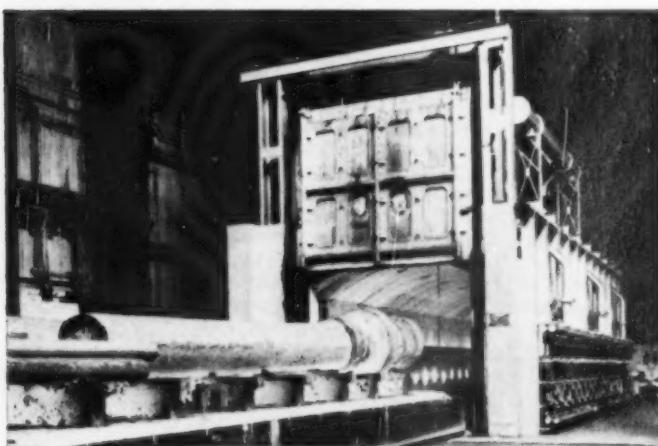
load from cold to 950°C. in 12 h. when necessary.

The larger furnace will hold a load in equilibrium at 700°C. with a gas consumption of approximately 5,500 cu. ft./h., and the smaller one will hold at similar temperature with a gas consumption of approximately 3,000 cu. ft./h. The ultimate annual load in this one department will be of the order of 300 mill. cu. ft.

Two other furnaces of original design have been installed by Beardmore for precision heat treatment at temperatures up to 950°C. (fig. 2).

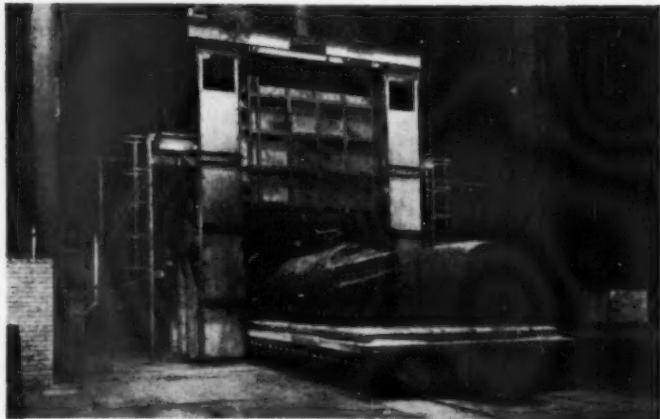
These two furnaces were constructed by Brayshaw Furnaces Ltd., of Manchester, and have internal dimensions similar to the Priest furnaces outlined previously. High-velocity forced convection is employed as the heating system, and, on the larger

of the two bogie hearth furnaces, six hot gas recirculation fans are fitted on the roof of the furnace. Each fan is rated at 22,500 cu. ft./min. of combustion products and air, and driven by a 30-h.p. motor. The furnaces are substantially lined with insulating refractory, as also are the six fan casings and connecting ducts. The heat input is provided from an air-blast burner firing into a combustion chamber fitted on the intake to each recirculating fan. Electronic flame failure equipment is incorporated on the main and pilot burner assemblies, together with fan failure protection. The combustion products are discharged into the furnace chamber through a multiplicity of ports built into the side walls of the furnace, with provision for independent adjustment to facilitate 'balancing'



1 Priest bogie hearth furnace

[By courtesy of William Beardmore & Co. Ltd.]



2 Brayshaw forced-convection bogie hearth furnace

[By courtesy of William Beardmore & Co. Ltd.]

of the furnace. After passing through the load, the gases are withdrawn through apertures in the crown of the arch and return to the fan intakes. With the high rate of recirculation provided for, a heat distribution within a tolerance of $\pm 1^{\circ}\text{C}$. is obtained. The smaller furnace is fitted with four recirculating fans, combustion chambers and individual burner assemblies, and both furnaces are fully instrumented by means of Honeywell Brown automatic temperature and pressure controllers, as in the case of the Priest furnaces. The maximum gas consumptions are 60,000 and 35,000 cu. ft./h. respectively.

Other new furnaces under construction for William Beardmore & Co. Ltd. include large muffle units for the precision hardening and tempering of 70-ton rolls, suspended vertically.

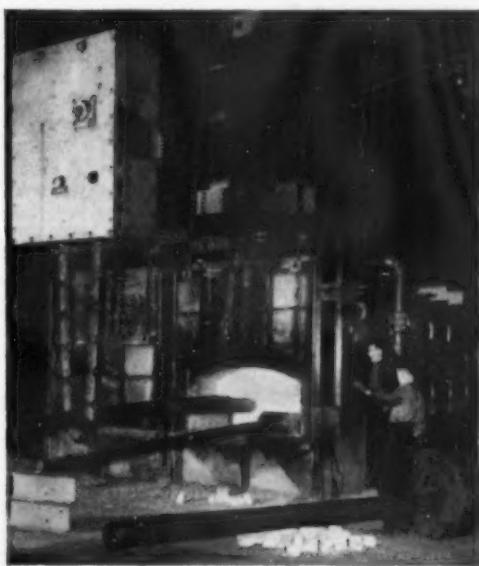
There are, of course, many other gas applications in this extensive factory, which have been in use for a number of years. Six Dowson & Mason portable-cover furnaces, 15 ft. \times 8 ft. \times 6 ft., are used for the stress relieving of castings, and eight bogie hearth furnaces, 20 ft. \times 10 ft. \times 4 ft., for general heat treatment; also, forge furnaces converted from producer gas; gas-fired ladle-heating equipment in the extensive foundry, etc.

The Dennystown Forge Co. Ltd.

The Dennystown Forge Co. Ltd. is a very old-established firm, located in Dumbarton, which has for many years produced high-quality finished forgings in considerable varieties, including turbine forgings, hollow shafting and all classes of engine forgings, mainly for the shipbuilding industry. Until recently, the company utilized solid-fuel-fired furnaces for heating ingots and for subsequent heat treatment of the forgings, but a number of

these have been replaced with gas-fired furnaces.

Fig. 3 shows a Gibbons furnace having internal dimensions of 12 ft. deep \times 9 ft. 9 in. wide \times 8 ft. 3 in. high from sill to top of furnace chamber, for heating ingots up to 32 tons in weight to forging temperature of 1,220–1,320°C. The normal procedure is to insert the ingot into the furnace at the beginning of the dayshift and to leave the furnace on automatic temperature control to bring the ingot up to temperature. The ingot is then soaked for the remainder of the night so as to obtain uniformity of



4 ABOVE Gibbons billet-heating furnace



3 LEFT Gibbons ingot-heating furnace
[By courtesy of The Dennystown Forge Co. Ltd.]

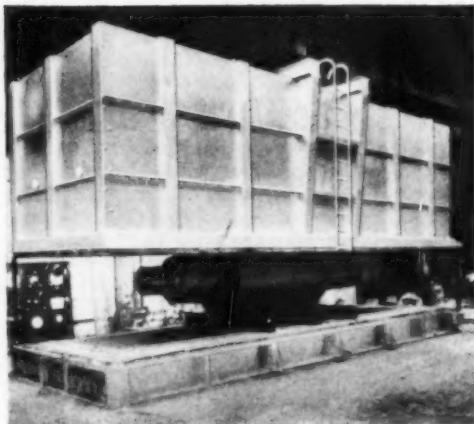
temperature throughout, and is ready for withdrawal, and working under a 2,000-ton press, the following day at 6.30 a.m. Usually, it takes from 6 p.m. until about 1 a.m. for the furnace to regain temperature after insertion of the cold ingot, and from that time until 6.30 a.m. to 9 a.m. to soak the ingot throughout so that it is ready for 'working.'

The furnace is fitted with Thermic Eddy Ray burners in each side wall, three burners being located on each side at low level, and three burners at high level so as to provide uniformity of temperature distribution. High/low temperature control is employed by means of motorized valves in the gas and air supply, operated from a Cambridge recorder controller. Following charging, and the bricking up of the space on each side of the ingot below the door, the forging is left entirely on automatic temperature control without manual adjustment in any way. A slight pressure is always maintained at hearth level by virtue of the stack draught being broken by means of an aperture provided in the base of the stack. This pressure is maintained irrespective of fuel input, thus preventing air infiltration and loss of efficiency by excess air, whilst scaling is, of course, minimized. A typical gas consumption for heating a 32-ton ingot to 1,220°C. is 190,000 cu. ft. at a calorific value of 450 B.Th.U./cu. ft.

Fig. 4 shows a smaller Gibbons furnace, having internal dimensions of 9 ft. 6 in. deep \times 13 ft. wide \times 5 ft. high from sill to top of furnace chamber, for heating billets of up to 8½ tons weight. Four Thermic Eddy Ray burners are fitted in each of the side walls, and the furnace has double twin doors so that four separate forgings can be heated to forging temperature at the same time. Cambridge high/low temperature control is again employed by means of motorized valves in the gas and air supply lines. The waste gases from this furnace pass from the back of the furnace, and, via a special flue, to a waste-heat boiler.

A Gibbons bogie-type annealing and normalizing furnace having internal dimensions of 16 ft. 6 in. deep \times 7 ft. wide \times 4 ft. 10 in. high from top of bogie to top of furnace chamber was completed and came into operation in October, 1959. It is used for heat treatment in a range 600–950°C., and is controllable within $\pm 5^\circ\text{C}$. Burners, fitted in each side wall, comprise six burners arranged to fire into combustion chambers in the bogie hearth in staggered formation, and five burners, at high level, set at an angle towards the centre-line of the main arch.

The outlet flues are located immediately inside the door, and the waste gases travel up into top flues running lengthwise at each side, and thence into a back flue leading to the chimney. The air for



[By courtesy of R. B. Tennent Ltd.
5 Dowson & Mason forced-convection portable-cover furnace

the top burners, which consume the bulk of the fuel when operating at the higher temperature level, is preheated by a recuperator embodied in the waste-gas flues in the top of the furnace.

The gas consumption averages 2.9 cu. ft./lb. when annealing forgings at 930°C. over a 12-h. cycle, and the annual gas consumption in a full year from all the new furnace plant should be 60 mill. cu. ft.

R. B. Tennent Ltd., Coatbridge

R. B. Tennent Ltd., of Coatbridge, Lanarkshire, are producers of high-quality cast-steel rolls, weighing up to 50 tons. Individual rolls are expensive items in the finished state, so that failures due to faulty heat treatment are a matter of serious concern. Precision heat treatment is, therefore, essential, and this company are most insistent that the tolerances it lays down in respect of temperature distribution and temperature rise should be closely followed. For the precision heat treatment of rolls at temperatures up to 650°F., a Dowson & Mason portable-cover furnace is employed.

Fig. 5 illustrates this furnace, which is 28 ft. long \times 7 ft. wide \times 7 ft. high and employs high-velocity forced-convection, involving two Peacock hot-gas recirculating fans rated at 50,000 cu. ft./min. each, against a resistance head of 2 in. w.g., to recirculate the gases throughout the working space at high velocity. The gas burner equipment comprises two Dowson & Mason 'target'-type air-blast burner assemblies fed with air from a separate combustion-air blowing fan at 1 lb./sq. in., combustion taking place in two separate refractory-lined combustion

chambers. The furnace is fully instrumented, electronic flame-failure equipment being fitted on the burner equipment. The wiring of the flame-failure amplifiers is arranged so that the two sets are paralleled up, this precaution ensuring that the plant shuts down if either burner fails. Spark ignition is incorporated to the air-blast pilot on each of the main gas burners. Air/gas ratio control is provided by means of square port valves fitted in the gas and air supply to each main burner. Honeywell Brown temperature/programme controllers give proportional control, and the output from these controllers is arranged to operate two Hagen power cylinders fitted to the respective square port valves. The furnace is capable of being accurately controlled to give a temperature rise of the order of $10^{\circ}\text{C}.\text{h}.$ with a differential of temperature within the furnace, when heat treating a 70-ton cast-steel roll, of not more than $\pm 2^{\circ}\text{C}.$

The overall gas consumption on a typical cycle, which would involve bringing a roll from room temperature to $550^{\circ}\text{C}.$ over 45 h. with subsequent long-cycle soak, would be 135,000 cu. ft. of gas for a 70-ton load.

For heat treatment at temperatures to $1,050^{\circ}\text{C}.$, a Mathison multi-zone gas-fired bogie hearth furnace is employed. This furnace, capable of taking loads of up to 100 tons, is 30 ft. deep \times 10 ft. wide \times 8 ft. high. Longitudinally, it is divided into three zones for automatic temperature control purposes, the manifolds serving these zones being fitted with special Mathison valves to give air/gas ratio control over the working range. Nine vertical-firing luminous-flame-type burners are fitted on each side of the furnace. Foster instruments are employed to give adjustable programme/temperature control, and the temperature rise can be controlled so as to not exceed $10^{\circ}\text{C}.\text{h}.$ Provision is included in the furnace for a measure of recirculation of the gases in the early stages, *i.e.* at the lower temperatures. Recuperation is also provided for by a metal heat exchanger incorporated in the flue offtakes. The maximum gas consumption of the furnace is 14,000 cu. ft./h. It is difficult to give performance data as the heat-treatment cycles, and loadings, vary appreciably and involve periods of time of up to 21 days.

The usual safeguards are provided by way of air-fan failure and low gas pressure protection, manual resetting being essential after close-down.

The annual gas consumption of these two furnaces

Change of address

High Duty Alloys Ltd. announces the transfer of its Birmingham Sales Office from Queen's College Chambers, Paradise Street, to 369 City Road, Edgbaston, Birmingham 16 (Bearwood 2344-5). All Forging Division sales matters will be dealt with at the Forging Division, Redditch, as at present.

is approximately 30 mill. cu. ft. A third furnace is under construction and further furnaces are projected.

Stewarts & Lloyds Ltd., Clydesdale Works, Bellshill

An unusual design of normalizing furnace is at present under construction by Priest Furnaces Ltd. at the Clydesdale Works of Stewarts & Lloyds Ltd. Special attention has been paid to the problem of progressing the tubes through the furnace, as tubes bow very rapidly if unevenly heated.

The furnace is 48 ft. 3 in. wide \times 14 ft. 7½ in. long, measured inside the brickwork.

A tube enters the furnace on skewed rollers and is thus rotated whilst being moved forward until its leading end touches a stopper, which stops the charging rolls and actuates the walking-beam, which lifts the tube from the rolls. The tube is then walked and slowly rotated across the furnace to the discharge rollers, which are also skewed. The rotation of the tube throughout its travel is aimed at obtaining uniformity of temperature.

The design capacity of the furnace is 5 ton/h., but 7 ton/h. will be possible on favourable sizes. The tubes are heated from cold to $950^{\circ}\text{C}.$ The combustion equipment consists of 17 tunnel gas burners applied through the discharge end wall. These burners are divided into two groups of six burners and one of five burners, forming three zones to each of which fully floating temperature control equipment is applied together with air/gas ratio control. A recuperator is installed in the flue system and furnace pressure control has also been applied.

These installations are representative of modern plant being installed in Scottish industry, and many major schemes, involving plant incorporating notable technical advances in thermal engineering, are going forward, or are under consideration. In total, new furnace plant at present on order will take an additional 1,500 mill. cu. ft./annum of gas by 1962.

Acknowledgments

In their original presentation the authors expressed their thanks to the Chairman of the Scottish Gas Board, Mr. Sydney Smith, C.B.E., M.Inst.Gas E., F.Inst.F., and Mr. H. R. Hart, T.D., Deputy Chairman, for permission to prepare and present their Paper.

They also extended their thanks to the companies concerned for their ready co-operation in furnishing operating data, as well as to the industrial staff of the Industrial Department of the Scottish Gas Board for assistance in the preparation of their Paper.

Magnetic quenching

AN ELECTROMAGNETIC quenching process in current use at Research Development Corporation of America, Gardena, California, is claimed to result in grain refinement in steel and titanium alloys giving high mechanical strength and ductility in the heat-treated condition.

Mr. William I. Bassett, III, RDCA research director and originator of the process, gave the following explanation.

During conventional heat treatment, a state of extreme thermal chaos is produced in an alloy by elevated temperatures. Consequently, the metal tends to retain a chaotic or non-uniform grain pattern when it is suddenly quenched in a medium like water or oil and it will be relatively brittle. On the other hand, if the alloy is moved into a strong electromagnetic field before it can cool appreciably, its nuclear components can be uniformly lined up. If it remains in the field until it is cool, the metal will retain its uniform alignment—which means it will have the very fine grain that is essential to high tensile strength and ductility.

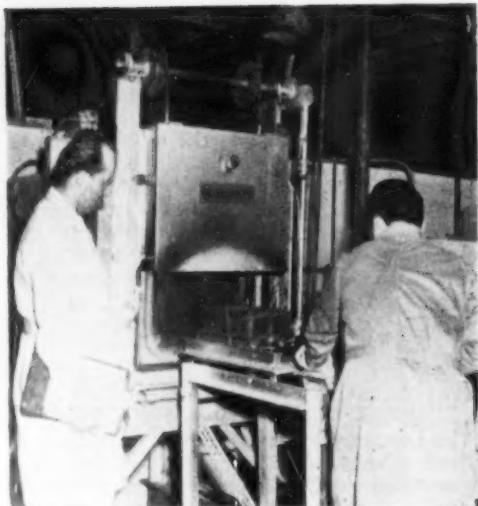
Advantages of the process

Comparisons show that RDCA's average yield and tensile values are about 50,000-100,000 lb. sq. in. higher than maximal values listed for identical alloys in manufacturers' literature. Of particular interest is the fact that yield point and ultimate tensile strength data for magnetically quenched metals are identical. Bassett explains this by pointing out that fine grain structures make it virtually impossible for plastic deformation to occur before the alloys have actually failed.

RDCA is using time-temperature cycles substantially different from those commonly employed in heat treatment. Most of the work to date has been accomplished with a standard Hevi-Duty furnace with inert atmospheric accessories as well as special facilities for magnetic quenching. Fields suitable for the quenching can be produced either by solenoids or electromagnets.

In some instances, electromagnetically quenched metals like 4340 steel retain permanent magnetic charges at temperatures below 150°C. This poses no special problem, Bassett avers, because the materials can be automatically demagnetized during a subsequent tempering operation at a temperature below 260°C.

Durkee Testing Laboratories recently ran a series of physical tests with identical 4340 steel specimens which were respectively treated by RDCA and another company. Results showed that, where the other company's 4340 specimens had yield points ranging from 228,800-233,500 lb./sq. in. and tensile



Basketful of small parts being treated at Research Development Corporation of America, California

strengths of 273,750-276,750 lb./sq. in., RDCA's specimens had both yield points and tensile strengths of 369,450-373,650 lb./sq. in. Elongation in RDCA's specimens simultaneously ranged from 5-6%, while the other company's had 10-11%.

Durkee's tests have further indicated that, in treating Zenalloy 312-WS, RDCA has been getting yield and tensile values of 150,000 lb./sq. in. Manufacturer's data shows that, where the same alloy is solution heat treated at 1,070°C. for 4 h. and air cooled, then stabilized at approx. 745°C. for 16 h. and air cooled, the best of obtainable yield and tensile values are generally below 50,000 lb./sq. in.

Possible applications

RDCA officials maintain that castings, forgings, stampings and machined parts respond equally well to the Bassett process; and that the process can be used to improve parts with any configurations and dimensions that can be conventionally heat treated.

By improving the properties of available metals, the Bassett process could eliminate the immediate need for developing new alloys in such fields as aircraft, rockets and missiles and may allow substantial cost reductions in other fields by permitting production with less expensive tools and materials. It might also enable steel to compete with aluminium where weight is an important factor. According to Bassett, it has already enabled some steels to attain a better strength/weight ratio than that of the strongest aluminium alloys now available.

Precision forging

Today, many different parts are forged to close tolerances so that little or no subsequent machining is required. For such items aluminum and magnesium are often used, but other metals offer more problems. A staff report in 'Metal Progress,' May, 1960, discussed some of the difficulties that forgers in the U.S.A. met and solved in research and in regular production. It is thought that some of the main points would be of interest to British forgers

FOR CONVENIENCE, precision forgings will be discussed under two general classifications, the division being determined by the relative ease of forging. The first group includes the light metals, aluminum and magnesium. Being forgeable at moderate temperatures, they are not difficult to maintain at heat while they are being shaped. Protecting the surface—a very important step in precision forging—is also fairly simple for these two metals.

As a consequence, the process is now being used quite widely for the light metals, particularly high-strength aluminum alloys. Tons of forged parts (chiefly for aircraft) have been turned out by the forging presses at Wyman-Gordon and Alcoa, two companies which are very active in precision and close-tolerance forging. Though original equipment costs much more, the saving in subsequent machining is such that the process is definitely economical. Machining large air-frame members from the conventional and blocker-type forgings formerly used was an expensive, time-consuming process which required elaborate and massive tracing lathes.

Aluminum and magnesium

Precision forging—or, more accurately, close-tolerance forging—of aluminum and magnesium has progressed much farther than it has for steel and refractory metals, for the reason that the light metals can be forged at much lower temperatures. Forging at 260–480°C. is common, and such temperatures are fairly simple to maintain. Usually the dies are warmed and held at the approximate forging temperature to facilitate metal flow into every section of the die.

Because of the continuing demand for lighter aircraft, much money has been invested by the government in very large forging presses to make close-tolerance forgings. Inspired by German

developments revealed after World War II, enormous 35,000- and 50,000-ton forging presses were erected at Wyman-Gordon's North Grafton (Mass.) plant and the Alcoa Forge Plant in Cleveland. These huge presses made it possible to forge large airframe sections with greatly improved tolerances.

The main problem comes in the cost of tooling. Dies for precision forgings are considerably more expensive than the simpler dies formerly used. Also, set-up time for a run of precision forgings is longer; this adds to the cost. As a consequence, a fair number of parts must be made if true savings are to be realized from precision-forging techniques. The break-even point, since it generally depends on the complexity of the design, will vary quite widely from part to part.

A good indication of the cost problem might be gained by considering some of the precautions taken by one producer. First, the bar stock has to be carefully inspected and prepared, as any surface imperfections will appear in the forging. The presses which forge this stock are built with precision features including, among other items, an automatic timer. (The 'dwell' time—the time during which pressure is maintained—is critical, and cannot be allowed to vary.) Every forging is weighed to within an ounce before the final pressing because there is no leeway for overweight (no allowance for flash) or underweight (thin webs do not fill in). All completed forgings are 100% inspected before shipment.

It is apparent that precision forgings are not easy to make. However, that is not the chief worry of forgers today. As far as they are concerned, the major drawback is the lack of demand for airframe sections. Because of the increased interest in missiles, work on newer aircraft has slackened, and this slackening is reflected in the forging field.

However, forgers would prefer to find a market much more dependable than either aircraft or missiles. Alcoa is moving in that direction with the forging of wheel discs for automobiles and truck trailers. Trowel handles, connecting rods, and equalizer beams for trucks have also been precision forged. It would seem that there is a future for this type of forging in the automotive field. Other areas where such forgings may also be useful are hydraulic equipment, large electronic equipment such as that in the radar and television industries, and atomic energy equipment. In general, precision forgings of aluminum can be used wherever light weight, strength, and close tolerances are all essential.

Other metals

Most other metals are forged at higher temperatures. Metals such as titanium, beryllium, molybdenum, tungsten, niobium, tantalum, and the

superalloys are difficult to forge as it is. The prospect of forging them to close tolerances as well is definitely not inviting to the average forger. Yet, the process is attracting attention because of the savings that can develop. The refractory metals and superalloys are expensive and any reduction in material loss is at once realized. Also, these metals are difficult to machine; cost reductions can also develop from both the reduction of machining time and the wear and tear on machinery.

So far, however, the numerous drawbacks that occur in forging the refractory metals have inhibited progress to a great degree. The high temperatures needed for forging bring a host of problems which must be solved before the process can become a routine matter. Surface protection becomes vital as, without proper protection, steels decarburize, tungsten and molybdenum oxidize rapidly, and titanium picks up appreciable hydrogen at the high temperatures which are needed. Holding precision tolerances under such conditions is very difficult.

Also hard to find are die materials which will withstand the wear that dies incur when used for forging at high temperatures. The property which makes a refractory metal useful at elevated temperatures—resistance to deformation—is the same property which makes the metal difficult to forge. Die materials must stand up to both the stiffness of the metal being forged and the high temperature. The material that can do this—whether it be a superalloy or a suitable die steel—is itself hard to shape to precise dimensions. Lengthy and costly machining may be needed merely to cut the die to the proper shape.

These and other problems have limited the development of precision forging in the refractory metal field. At present, the only types of parts being precision forged to any extent are turbine blades for jet aircraft. Forging of other types of parts is still in an experimental stage.

Recent U.S. research

Just over a year ago, a research programme on close-tolerance steel forging was sponsored by the Air Materiel Command. Through Boeing Airplane Co., who handled the prime contract, three forging companies (Ladish Co., Steel Improvement and Forge Co., and Wyman-Gordon Co.) were assigned various projects. Each company was to forge (of A.I.S.I. 4340) a different production item, redesigned as a precision part. The approach to be investigated by Ladish was 'multiple dies and multiple parting lines'; by Steel Improvement, 'high-speed mechanical presses or impacters'; and by Wyman-Gordon, 'dies heated to the approximate temperature of the forging stock.' In the time allotted each company was asked to produce

a number of production parts for testing by Boeing.

Multiple parting lines and dies

As already mentioned, Ladish Co. was asked to investigate multiple dies and multiple parting lines. Drop hammers were to be used for the forging. The part was forged with the web in a horizontal position so that the forging could be positioned exactly. After finish forging, hot coining dies produced the precise dimensions that were needed. Locks in the blocking and finish-forging dies helped to maintain precise alignment. Flash was eliminated before the hot-coining operation, and close temperature control was needed at all stages.

Ladish D 6 A (hot-work die steel containing 0.46% C, 1.0% Cr, 1.0% Mo and 0.50% Ni) was used for blockers and finish-forging dies.

Die temperatures were 180—320°C. throughout the forging, except for hot-coining inserts which were run at higher temperatures. Decarburization was minimized by using a furnace atmosphere of nitrogen and pine oil, and the forgings were also coated with 'Aqua-Dag,' a suspension of colloidal graphite in water. These procedures were quite effective in minimizing decarburization, according to Boeing, who subsequently tested the 51 production-type forgings made by Ladish.

At the ultra-high-strength levels (260,000—280,000 lb./sq. in.) to which the steel is treated, the minor decarburization level of 0.002—0.0025 in. did not act to limit the fatigue strength. In fact, an improvement in fatigue strength was reported. The forgings also had adequate dimensional precision. On the whole, the Ladish phase of the research was considered a success.

High-speed techniques

Meanwhile, Steel Improvement and Forge Co. was investigating high-speed-forging techniques with an impacter (a patented tool designed and manufactured by the Chambersburg Equipment Co., Chambersburg, Pa.). Since it was thought that metal would flow through thin sections at high speeds if heated dies were used, the researchers experimented with dies made from a material which could withstand a high temperature. In the preliminary tests, the die blocks (solution-treated and aged) were ground flat and used to evaluate lubricants since lubrication at high temperatures was also considered a problem. Three lubricants, all of which contained colloidal graphite, were tested.

These tests showed that forging at about 320°C. die temperature with colloidal graphite for lubrication was the most practical method for precision work. Above this temperature, lubrication becomes difficult and dies are more likely to deform to the

point where the needed precision cannot be maintained.

As a consequence, Steel Improvement gave up the attempt to forge at high temperatures, and settled on S.A.E. A-2, a high-carbon die steel, for the die insert material. Compared to conventional hot-work steels, A-2 has greater compressive strength and wear resistance, qualities which are desired in dies for precision forging.

Early tests indicated that decarburization of the 4340 would exceed the maximum of 0.010 in. required by the programme. Since nickel coatings were known to prevent decarburization, they were the subject of some experimental work. It was found that such coatings were successful for short times, but offered little protection when longer times at the forging temperature were involved. Thicker coatings of nickel did not improve surface protection to a significant degree. When argon (under a constant flow) was used as a protective atmosphere on the furnace, decarburization was limited somewhat. However, it seemed that another approach was necessary.

Therefore, it was decided to try removing decarburization *after* it was formed rather than trying to prevent its formation. Since chemical-milling processes looked quite promising, they were investigated. Tests with nitric acid proved that chemical milling was practical. About 0.02 in. was removed from the surface every hour, and metal removal was fairly constant in depth over the surface. In actual tests, an average of 0.0082 in. was removed in 25 min. Programme time ran out before the production run of test forgings for Boeing could be made, but few problems remained at that time.

Heating dies

The attempt (by Wyman-Gordon researchers) to evaluate heated dies ran into trouble almost from the outset. To begin with, René 41 was selected for the dies because of its excellent strength at elevated temperatures. However, this alloy also turned out to be extremely hard to machine to precision tolerances. The cutting tool used to complete the finish machining, for example, bent away from the metal rather than cutting into it. This work hardened the surface, making it even more difficult to machine. Many tools were broken during this effort.

Heating the dies to the required temperature also was a problem. Induction methods appeared promising, but were abandoned when the high frequencies which were needed could not be obtained at the forging press. Globars were eventually used, but were too brittle to withstand stresses which developed during forging.

Finally, five tryout forgings were produced by

the setup; however, none of them was satisfactory as far as required specifications were concerned. Much more research is needed if this approach—heating dies to approximate temperature of forging—is to be a success.

Cast dies

The solution to this particular problem might be found in cast-die materials. In some recent research conducted at Armour Research Foundation, Inco 713 C turned out to be a highly satisfactory die material, since it could be heated to 870°C. for forging. The dies themselves were cast in moulds made from granulated graphite. This technique gave them a very smooth finish and optimum metallurgical properties. Slots for calrod heating units (needed to maintain the high die temperatures) were also cast into the die bases. The technique was experimental, and precision in forging dimensions was not the primary aim, but, in spite of this, it seems a promising technique for making precision forging dies.

To sum up, like most innovations, precision forging has its advantages and disadvantages. Admittedly a costly technique, particularly when processing the harder-to-forgo metals, its potential is that savings can be realized in both material usage and machining.

APPLIED PHYSICAL CHEMISTRY FOR METALLURGISTS

A COURSE of ten lectures will be given by J. Mackowiak, Ph.D., A.I.M., on Wednesdays, 2.30-5 p.m., commencing 12th October, at the Metallurgy Department, Battersea College of Technology. The course has been arranged for metallurgists, metallurgical chemists and physicists who, having completed formal studies some years ago, may like to review the present state of knowledge of Thermodynamics, Kinetics and the electronic configuration of elements and their application to Metallurgy. Ample opportunity will be given for questions and discussion.

The syllabus includes an introduction to physical and mathematical concepts of the structure of atoms; simple electronic theory of ionic, covalent and co-ordinate compounds, with special emphasis on the relationship between their structure and their physical and chemical properties; metallic bond, conductors, semiconductors and insulators; comparison between the scope of thermodynamics and kinetics; simple explanation of intrinsic energy, heat of reaction and enthalpy, entropy and free energy, and their physical meanings; basic concepts and scope of kinetics; Arrhenius equation and its application to chemical and physical processes; kinetic theory of simple chemical reactions; energy of activation and free energy; order of reaction; regulating steps of processes with a particular emphasis on some metallurgical processes, such as precipitation and growth, the influence of temperature and concentration on the velocity of reaction in a closed system; Application to Practical Problems—Extraction and refining; equilibrium phase diagrams; corrosion of metals.

The fee is £1 and enrolment forms may be obtained from the Secretary (Metallurgy Courses), Battersea College of Technology, London, S.W.11.

Vacuum annealing

British bell-furnace plant

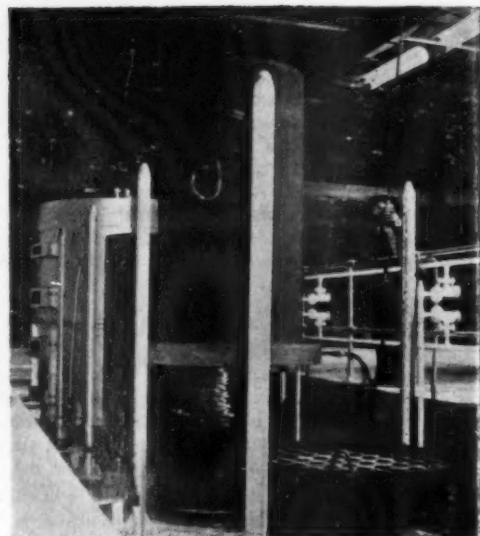
A BELL FURNACE installation for the vacuum annealing of copper wire, the first British-made installation of its kind, has recently been put into operation in the Hazelhurst Works, Ramsbottom, Manchester, of F. D. Sims Ltd. The plant was designed and supplied by the Electric Resistance Furnace Co. Ltd. It uses an Efco bell furnace, transported by an electric travelling crane to serve six bases where the copper wire, in coils or wound on reels, is heated in vacuum-tight containers.

The bases accommodate a stack of wire up to 3 ft. dia. by 4 ft. high, the actual weight of a charge depending upon the size of coils or reels being processed, the maximum weight being about 3,500 lb. The wire is normally heated for 4 h. and then left to cool for from 12 to 20 h. before being exposed to atmosphere. The installation is designed to anneal 34 tons of wire in a working week of 120 h.

In the short time that has elapsed since the commissioning of the plant excellent results are said to have been achieved. The wire is fully annealed, it is maintained in a clean and bright condition with complete freedom from sticking between turns. Whilst the plant and its method of operation are similar to many controlled atmosphere bright-annealing installations, the use of vacua is claimed to be more economical when compared with the costs of installing and operating a controlled atmosphere generator.

Furnace details

The furnace bell is rated at 85 kW. and can operate at temperatures up to 550°C. It has a cylindrical casing of mild steel plate containing adequate heat insulation with a refractory lining and being designed to minimize the stressing of the refractory by the repeated raising and setting down of the furnace. The bell is heated by coils of nickel-chromium wire supported around the circumference of the chamber on sillimanite tubes and arranged in three zones, the temperatures of the zones being independently controlled with automatic indicating instruments. The furnace is accurately positioned over a base by guide posts and the electrical connections are made automatically.



The Efco bell-furnace vacuum annealing installation at F. D. Sims Ltd., Manchester. Lowering a self-sealing hood over a charge of copper wire

The six bases, which are arranged in a shallow pit to allow sufficient headroom, all have a vacuum-tight steel casing, filled with heat insulation, and carrying on the top a steel charge stand designed to position the charge well into the hot zone of the furnace chamber. The vacuum containers are of plain cylindrical shape with welded, dished tops carrying a single lifting lug. At the bottom of the containers there is a heavy sealing ring having a machined surface which engages with a water-cooled rubber seating surrounding the hearths.

The operating vacua are obtained with 'Speedivac' pumping gear supplied by Edwards High Vacuum Ltd. For the initial purging of a container an air-ballasted roughing pump with an air displacement of 15 cu. ft./min. is used. The process pump has a displacement of 30 cu. ft./min. Either pump can be connected through vacuum valves to any one of the bases.

The installation is easily managed by a single operator, who stacks the charges on the carriers, places the carriers on the bases below the self-sealing vacuum containers, operates the vacuum pumping equipment and moves the furnace. Throughout the heating period the charges and the furnace bell are protected from overheating by a safety device which gives an aural alarm and cuts off the supply of the furnace elements.

Annealing and hot working high-nickel alloys

TO ASSIST THE WORKING of high-nickel alloys (a term which in this article includes nickel itself unless otherwise stated), there are five forms of annealing which can be used: soft, dead-soft, temper or partial, low-temperature or stress-equalizing and bright annealing. Some high-nickel alloys may be cooled from annealing either rapidly or slowly, but for precipitation-hardening high-nickel alloys, such as 'K' Monel, the cooling must be rapid. It is advisable briefly to survey these forms before considering the various hot-working methods.

In soft annealing the metals must be protected against embrittlement and excessive oxidation; this is effected by using non-scaling atmospheres with low sulphur content. The combustion reactions in the furnace should be complete before the hot gases strike the metal and, to avoid excessive grain growth, the temperature and time at temperature must be controlled. To prevent injury to the metallic surface, fuel of low sulphur content should be used; the heating atmospheres must be free from active oxygen; the work cleaned to remove all harmful ingredients, and so supported that it is out of direct contact with scale, slag or cinders on the hearth of the furnace.

Open annealing, applicable to all high-nickel alloys, is generally used for bright annealing. Nickel is open annealed for drawn shapes and spinnings either at 815°C. for 3-6 min., or at 925°C. for 1-4 min., intermediate times and temperatures varying directly with these extremes; nickel-copper alloys (not heat-treatable), such as Monel, for 5-10 min. at 870°C. to 1-4 min. at 980°C.; and nickel-chromium-iron alloys, such as Inconel, for 7-15 min. at 980°C. to 2-5 min. at 1,065°C. More time is required for closed, box or pot, annealing, because of the lower temperatures used, thus temperature control is not so critical; and because the work is protected from the furnace atmosphere, the type of furnace and the fuel used are not as important as in open annealing. Nickel is close annealed for 3 h. at 705°C., 1 h. at 760°C. or $\frac{1}{2}$ h. at 815°C.; nickel-copper alloys for 3 h. at 760°C. or 1 h. at 815°C., and nickel-chromium-iron alloys for 3 h. at 870°C.

For special work with small parts, salt-bath annealing is often used. Inorganic salts—carbonates and chlorides of potassium and sodium—are melted in large containers, for which purpose steel pots can be used up to 700°C., but at higher temperatures heat-

resisting nickel-chromium-iron alloy pots are better; ceramic containers are used for neutral salt baths working at 750-900°C., heated electrically by immersed electrodes. Four mixtures are in common use: 56% (by weight) of potassium and 44% of sodium chlorides, which melts at 660°C. and has a working range of 700-815°C.; 72.6 sodium chloride and 27.4 sodium fluoride, melting at 675°C. and working from 730-815°C.; 70 barium, 15 calcium and 15 magnesium fluorides, melting at 790°C. and with working range from 845-925°C.; and 83 barium chloride with 17 barium fluoride, melting at 844°C. and working from 900-1,000°C.

In electric-resistance annealing a current is passed through the work which, being a resister, heats rapidly. But in this process, unless the material is uniform in size, temperature control is difficult, and a suitable reducing atmosphere for bright annealing cannot be obtained. If the work is annealed for longer times and at higher temperatures than those given above, dead-soft annealing is obtained, when the hardness ranges from 10-20% lower than in the soft condition, but this degree of softness means corresponding increase of grain size—which may be undesirable. Temper, partial or semi-annealing, means heating hardened metal at a temperature and for long enough to achieve only partial softening; it is generally used for light sections such as strip and wire, but also for all other cases in which full annealing may not be required. Any of the annealing methods mentioned above can be used but a continuous method is best, with careful regulation of time at temperature.

In order to develop the best combinations of strength, ductility and machinability, cold- or hot-worked high-nickel alloys need low-temperature heat treatment. This process, which does not relieve or remove stresses, or alter the grain structure, homogenizes the material by spreading local concentrations of stress; thus it is correctly called 'stress-equalizing annealing.' Table 1 shows the effects of soft, stress-equalizing and temper annealing on the mechanical properties of the nickel-copper alloy Monel in the cold-drawn condition. Similar results are obtained with nickel, but nickel-chromium-iron alloys can be stress-equalized up to 425°C. without decrease in strength. With precipitation-hardening nickel-copper-aluminium alloys, such as 'K' Monel, although slight age-hardening results after heating at these low temperatures, this treatment is not necessary after age-hardening.

TABLE 1 *The effect of annealing temperature on mechanical properties at room temperature of a 1½-in.-dia. cold-drawn Monel rod (Henry Wiggin & Co. Ltd.)*

Three hours at temperature, °C.	Proportional limit, ton/sq. in.	0.5% Proof stress, ton/sq. in.	Maximum stress, ton/sq. in.	Elongation on 2 in., %	Hardness, D.P.N.
0	20.1	44.4	48.4	20.5	220
200	27.9	46.0	49.6	20.0	240
250	30.1	46.5	50.5	20.0	240
300	31.2	45.1	50.2	20.8	230
350	29.7	43.7	49.8	22.2	220
400	26.8	40.7	49.1	25.2	210
500	25.9	36.2	46.2	27.0	205
600	23.4	32.6	44.3	30.8	184
700	10.0	15.2	37.8	44.2	120
750	8.9	15.1	37.3	43.5	115

Stress-equalizing annealing 200–300°C.; temper annealing 400–600°C.; soft annealing 750°C. Specimens heated for 3 h. and air-cooled.

Cold-drawn nickel and nickel-copper alloys should be stress-equalized at 275°C. and nickel-chromium-iron alloys at 425°C. The proportional limit of a 1-in.-dia. cold-drawn Monel rod (20% reduction), as drawn, is about 17.9 ton/sq. in.; stress-equalizing annealed at 275°C. for 1 h., the proportional limit rises to 36.6 ton/sq. in.; for 2 h., the same; for 4 h., falls to 36.2; for 8 h., 35.7; and for 16 h., still 35.7 ton/sq. in. The optimum time and temperature for stress-equalizing hot-worked nickel-copper alloys is 3 h. at about 575°C. For bright annealing most high-nickel alloys the atmosphere should not only be free from oxygen but must contain certain proportions of the reducing gases carbon monoxide or hydrogen; but for nickel-chromium-iron alloys the best results are obtained in an atmosphere of cracked ammonia.

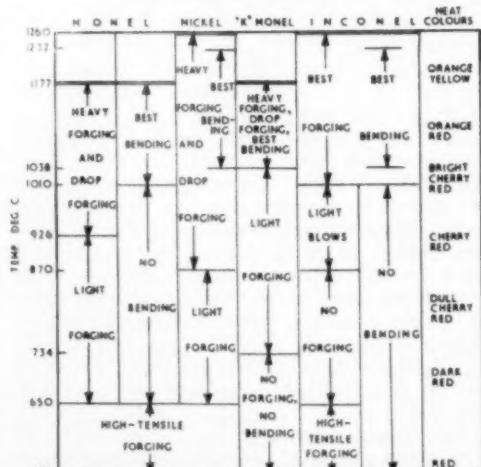
Hot working

The susceptibility of high-nickel alloys to sulphur during heating cannot be over-emphasized. Surfaces which have been thus attacked look, and often are in fact, simply burnt, and thus useless; which is why fuels which have a high sulphur content should never be used. The best fuel for heating these alloys for hot working is gas. It needs only small combustion space and, with modern equipment, facilitates regulation of temperature and atmosphere in the heating compartment.

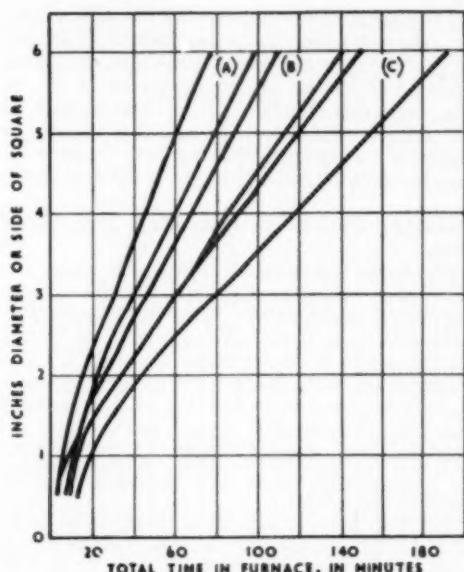
Town gas, which is low in sulphur, is satisfactory for these alloys, and several methods are available for purifying the gas from sulphur, such as the Gas, Light and Coke Co.'s catalytic process, the Maxted catalytic process, or treatment with activated carbon. Gas is particularly useful in small furnaces for heating all kinds of light work. Butane and propane are good alternative fuels. Other potential sources of the undesirable sulphur are scale, slag and cinder on the hearth of the furnace, already mentioned; the possibility of the furnace brickwork containing sulphur from previous operation on high-sulphur fuels; marking paint often

contains metallic sulphide pigments; and sulphur can be introduced as sulphate salts and sludge remaining from a previous pickling operation or in oil and lubricants used for machining or other fabricating operations. All such contamination should be minimized, and removed wherever possible.

Fig. 1 shows the temperature ranges for hot forging and bending high-nickel alloys. It can be seen that the alloys show important differences in hot-working temperatures—especially in the upper safe-heating limits and tendencies towards reduced hot ductility. While the alloys are being heated, the furnace temperature should be held at about 30°C. higher than that at which the work is to be 'pulled,' and in no case should it be pulled at temperatures below 1,100°C. Furnaces should never be worked at excessive temperatures in order to reduce heating



1 Approximate temperature ranges for hot-forging and bending nickel and high-nickel alloys (Henry Wiggin & Co. Ltd.)



2. Approximate time required for heating nickel and high-nickel alloy bars of different sectional dimensions (Henry Wiggin & Co. Ltd.)

time. Controlling and recording pyrometers should be used whenever practicable, but in their absence trials can be made on scrap pieces to assist the judging by colour of proper temperatures for hot working; a useful bend test for this is described later.

High-nickel alloys should be heated for only sufficient time to ensure that the correct temperature has been attained uniformly throughout the work. It is unfortunately not possible to give any definite rules for governing the time of heating, as furnaces and their operation vary so widely, but approximations are given graphically in fig. 2, *A* representing nickel, *B* nickel-copper with or without aluminium, and *C* nickel-chromium-iron. Short slugs receiving heat from all sides need about 40% less time, while flat slabs and plates require about 75% additional time.

During heating for hot working, scaling must be avoided. If sulphur-free fuel is used, the furnace atmosphere should be adjusted to contain at least 2% carbon monoxide. Slight excess of fuel over air is all that is usually needed; the closer the atmosphere is to neutral the easier it is to hold the required uniform temperature. The atmosphere must not be allowed to fluctuate between reducing and oxidizing. A slightly reducing condition can be effected by decreasing the air supply until there is a tendency to

smoke—indicating excess fuel and therefore a reducing atmosphere; the air supply should then be slightly increased to give a soft flame. The stack dampers are then wholly or partially closed, to force the gases out under the furnace door; the slight pressure thus set up in the furnace prevents the entrance of any air. The temperature should be at the upper limit of the hot-working range before the work is put in.

High-nickel alloys can be forged into products of the highest quality and into almost any shape that can be forged in steel. Die forgings, including conveyor chain links and hooks; hammer forgings, including large-diameter bars for shafting and hollow-bored tubing, seamless forged rings, and pickling hooks can be produced, and hydraulic or mechanical press forgings such as pipe fittings and valves. Such forgings are stronger than those in bronze or carbon steel unless it has been subsequently heat treated.

Corrosion-resistant forgings for applications where unusually high mechanical properties are required can be made from heat-treatable alloys; the forging characteristics of these alloys do not differ basically from those of nickel-copper alloys, but there are certain considerations which are mentioned later. Before heat treatment, the correctness of all conditions should be verified. A test bar of convenient size— $\frac{1}{2}$ -in.-dia. round rod or 1-in. by $\frac{1}{2}$ -in. flat bar—should be heated and held at the required temperature for 10–15 min. It is then water-quenched or air-cooled and bent through 180° flat on itself. There should be no sign of cracking.

If the conditions as described have been observed, there will be little difficulty in forging, pressing or bending. High-nickel alloys are stronger and stiffer than plain carbon steel at forging temperatures, so that a machine which has to be worked at full load to produce steel components will probably not be able to produce satisfactory forgings in these alloys. It is, therefore, often better to use heavier hammers and larger machines than would be needed for shaping mild steel—which applies especially to single-blow operations, such as heading rivets or bolts, or pressing.

Although the general hot-working procedure and temperature ranges for heat-treatable alloys are similar to those of other high-nickel alloys, their heat-treatability has to be borne in mind. If it is necessary to re-heat such material to complete the work, it should be at once recharged into the furnace; when hot-working has been completed, or when it is necessary to allow the metal to cool before further hot work, it should be quenched, from about 795°C , in water containing about 2% by volume of alcohol, because if this is not done the part will self-heat-treat to some extent during cooling, setting

up stresses that could result in cracks or surface tears during either such cooling or subsequent heating; any such material that has been air-cooled from about 700°C., instead of being quenched, may well become too hard for cold-forming or machining; and, finally, no attempt should be made to increase the strength and hardness of forgings in such alloys by semi-cold forging, because such efforts will only result in damage to the material and, further, the properties of a hot-finished and a semi-cold-finished forging happen to be essentially the same.

Die blocks for drop forgings or pressings can be made of either straight carbon or alloy steels, depending mainly on the shape and size of the work, the quantity required and the material to be forged. Dies of 0.8% carbon steel, hardened and tempered to 450 D.P.N., have long lives with small forgings in nickel and nickel-copper alloys. Plain carbon steel dies should not be heated above a temperature which gives a hardness value of 450 D.P.N. because the heat of the forged metal will reduce the hardness and may even crack the die. Alloy steel dies are generally better than carbon steel dies—in fact they are essential for large or intricate shapes in nickel or nickel-copper alloys and for all forgings in nickel-chromium-iron alloys except the smallest and simplest shapes.

High-speed steel should be used for trimmer dies with the cutting edge having a considerable rake; trimming can be effected either hot or cold. High-nickel alloys tend to stick in the die more than does steel. Sawdust thrown into the die is useful in preventing such sticking, but a swab with a mixture of heavy grease and graphite ensures proper clearing of the work from the die. Dies should be pre-heated before forging high-nickel alloys because cold dies chill the surfaces excessively.

Tensile properties of some high-nickel alloy forgings are given in Table 2. When forging is carried out in the lower part of the temperature ranges given in fig. 1, the maximum stress and proof stress values will approach the higher figures. The strength of hammer forgings can be improved by further careful hammering after the metal has cooled to 650°C.

Unusually good properties can be obtained on heat-treated nickel-copper-aluminium alloy forgings: test pieces taken from 'K' Monel stems

12½ ft. long and 6 in. dia., and 18½ ft. long and 7 in. dia., showed a limit of proportionality of 40 ton/sq. in., 0.2% proof stress of 49 ton/sq. in., maximum stress of 68 ton/sq. in., elongation of 24.7% on 2 in., reduction of area of 41.6%, and hardness of 300 D.P.N. Such forgings are heat treated by being held at about 590°C. for 8–16 h. after the mass has attained the same temperature throughout.

Auxiliary factors in annealing high-nickel alloys

Successful annealing of high-nickel alloys depends mainly on the control and uniformity of the annealing temperature; for which purposes indicating-controller and controller-recording pyrometers should always be used, preferably with thermocouples as shown in Table 3, the accuracy of which should be checked every day. Chromel-Alumel and iron-T.C. ferry couples should not be used for more than three months without changing, but the platinum couples can be used as long as they are found to be accurate.

Thermocouples should be so situated that in all parts of the furnace the desired temperature is maintained and the temperature of the work itself is also accurately measured. When, as is often advisable, two thermocouples are used, one should be as near the work as possible and the other near the heating elements. If only one is used, then it must be at the heating elements. In box heating the couple should be as near as possible to the centre of the work being annealed. The thermocouple in the furnace chamber regulates the annealing temperature while the thermocouple in the charge is connected to a recorder, the two showing the difference in temperature between the furnace and the box.

In electric furnaces thermal control is comparatively easy, but in gas-fired furnaces provision has to be made for the circulation of the gases. Unless the grain size is not important, the furnace temperature should never be more than the required annealing temperature. Forced-air circulation furnaces are generally the best—in economy as well as accuracy—for effecting low-temperature treatment up to 700°C. A strongly oxidizing atmosphere should never be used for annealing high-nickel alloys because the heavy oxide formed thereby—

TABLE 2 Range of tensile properties for forgings (Henry Wiggin & Co. Ltd.)

Metal	Maximum stress, ton/sq. in.	0.5% Proof stress, ton/sq. in.	Elongation, % on 2 in.	Reduction of area, %	Hardness, D.P.N.
Monel	36–49	18–38	40–20	70–50	140–230
Nickel	29–47	9–36	40–25	70–50	97–215
Inconel	38–54	16–40	45–20	70–50	145–230
'K' Monel:					
As forged ..	40–54	18–40	40–25	—	150–240
Heat-treated ..	60–74	45–56	30–20	—	260–310

TABLE 3 Thermocouples and protection tubes for use in heating and annealing nickel and high-melting alloys (Henry Wiggin & Co. Ltd.)

Thermocouple	Maximum temperature for prolonged operation, C.	Protection tube	
		Reducing atmosphere, CO or H ₂	Oxidizing atmosphere, O ₂ *
Platinum v. platinum (90%)-rhodium (10%) . .	1,370	{ Porcelain Mullite† }	None
Chromel v. Alumel	1,090	{ Inconel or 37/18 Ni-Cr-Fe alloy‡ }	None
Iron v. T.C. Ferry	870	Nickel or Inconel	None

* Although bare wire may be used, a protection tube decreases oxidation, especially with the iron/Ferry thermocouples and to a lesser extent with Chromel Alumel.

† The use of a porcelain primary tube inside the Mullite tube is recommended in reducing atmospheres at temperatures above 870 C. Nickel seamless tubing with one end closed by welding is generally used to protect the tubes from mechanical shock. The thermal conductivity of nickel is sufficiently high to prevent undesirable 'lag.'

‡ A special type of metallic sheath is recommended for these conditions. Means are provided for positive ventilation of the interior to minimize the effect of any gas diffusing into it (Birlec Patent 461,370).

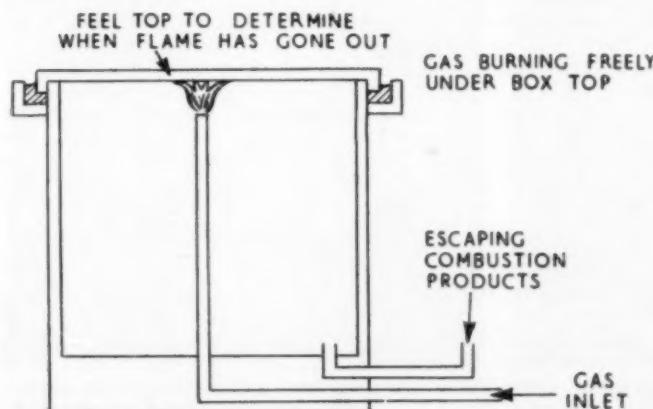
whether or not it can be removed by grinding or pickling—can be harmful to the underlying metal. A protective atmosphere must, of course, be so composed as to be non-oxidizing and free from other impurities such as sulphur, the best atmospheres being derived from anhydrous ammonia or fuel gases.

Assuming a source of clean, dry, oxygen-free hydrogen or cracked ammonia, and no moisture in the equipment, it must still be ensured that the furnace chamber or heating box is completely purged of air and other undesirable gases. In order to avoid the likelihood of an explosion, for batch-type furnaces in which cracked ammonia or hydrogen is to be used, purging with an inert gas is essential.

Fig. 3 shows a method of purging boxes. The situation of the charge allows plenty of space for gas to circulate between the parts. Before replacing the cover of the box, hydrogen is made to enter through the inlet tube and lit, the flame being

adjusted to about 1½ in., when it will burn against the replaced top. The cover is then put on the box and sealed with clay or sand, the bottom outlet tube being left open to let air and combustion products escape. When no air is left the flame naturally goes out; this cannot be seen but it can be felt by the top of the box just above the flame becoming cooler. Finally, without interrupting the flow of gas, a manometer is connected to the outlet which enables the flow to be controlled until it shows a positive pressure in the box of not less than 0.2 in. of water—when there is a slow escape of gas bubbles through the water in the tube. The box is then put into the furnace for the annealing.

Another way of regulating the pressure—which is, however, neither so reliable nor so economical—is to light the gas coming from the outlet tube instead of connecting the tube to a manometer. In this case the flame must be adjusted to a length of about 1½ in. If the end of the line is fitted with an



3 Flame method of a heat-treating box. (Henry Wiggin & Co. Ltd.)

orifice, jet or valve, waste of gas by using this method will be avoided. When annealing has been effected, the box can be cooled either in or out of the furnace. The flow of reducing gas must be increased to maintain the pressure at 0.2 in. When the temperature becomes less than 260°C. the work can be removed, because there is then no danger of oxidation.

Cold working has an important bearing on the control of grain size: the more the amount of cold work done, the lower is the annealing temperature—or the shorter the time required at original temperature—for producing the same degree of softness without increase of grain size. Heavily cold-worked hard-nickel-copper alloy softens quicker than half-hard-nickel-copper alloy only a quarter (to 75% of original thickness) cold-worked. The ductility of high-nickel alloys and nickel after annealing is also influenced by the amount of any cold work done: when only about 10% reduction in thickness is effected, full ductility cannot be restored by annealing; at least 20% of cold working is needed between anneals in order to restore full ductility and softness after annealing.

If the metal is cold-worked too much, it fractures internally and becomes scrap; the thickness of nickel and high-nickel alloy sheet and strip should not be reduced by more than 50% by spinning or deep-drawing. Nickel and high-nickel alloys harden quicker than aluminium or copper, which is why more than 50% cold work cannot normally be done between annealing operations. The softness of annealed high-nickel alloys is not affected by either slow cooling or quenching, thus quenching saves time—and also minimizes oxidation. Exceptions to this rule are the heat-treatable nickel-copper alloys, which precipitation harden during cooling and which should, therefore, be in any case quenched after annealing. Coarse-grained material should not generally be cold worked, as the grain of non-precipitation-treatable high-nickel alloys or nickel cannot be refined by what is known as 'normalizing' in steel. A coarse grain in high-nickel metals can be removed only by severe cold working followed, as a result of soft annealing, by recrystallization. The condition known as 'soft temper, fine-to-medium grain' describes the state of the metal when maximum workability has been obtained by annealing, to remove the effect of cold working without permitting appreciable grain growth.

When nickel and high-nickel alloys are heated in atmospheres that fluctuate between oxidizing and reducing, intercrystalline attack and embrittlement will occur—even in a sulphur-free atmosphere. Several lubricants which are used for spinning and deep-drawing contain sulphur and lead; these, and any other lubricants, paint or foreign matter, must be completely removed by washing—preferably

with trichlorethylene, carbon tetrachloride or trisodium phosphate—otherwise embrittlement may occur.

Apart from wrong furnace atmospheres or oil and dirt on the metal, furnace and box spallings and pick-up of other kinds also discolour nickel and nickel alloys. Parts which are to be heated in a furnace should not be put on an uncovered hearth. A sheet of nickel or heat-resisting alloy should be used for covering the hearth, or the parts should be put in a container for handling both in and out of the furnace. A cover or metal roof lining should also be used to protect the parts from matter falling from the furnace roof. Heat-resisting nickel-chromium-iron alloys are especially suitable for the containers or furnace linings.

THE EMISSION MICROSCOPE

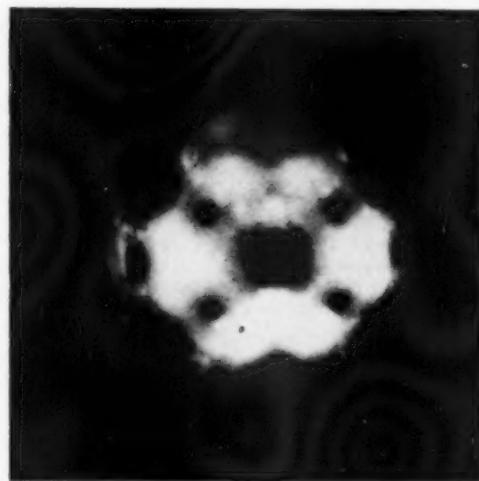
IT IS AN ESSENTIAL FEATURE of catalysis that molecules are adsorbed on the surface of the catalyst. At the Amsterdam laboratories of the Royal Dutch/Shell Group, the field emission microscope is being used to observe the mechanism of adsorption and to study the nature of the interaction between adsorbed molecules and the catalyst surface. The various crystal faces of the catalyst differ in catalytic activity owing to differences in geometrical structure, and the emission microscope permits a study of these differences.

The field emission microscope, or Müller projector, has been under development as a research tool for the past ten years, but this is believed to be the first time that it has been applied by industry. It operates on the principle that most substances will emit electrons when a high voltage is applied to their surface, which is the same principle by which the television tube works.

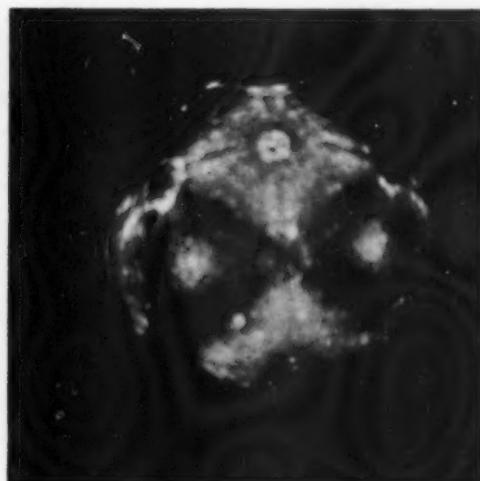
The microscope consists of a glass tube, one side of which has been coated with a fluorescent material to form a viewing screen. This screen fluoresces when hit by electrons which come from the metallic catalyst crystal under observation. The electrons are accelerated towards the screen by an electric field of the order of 30 MV./cm., and as a result they form a greatly magnified image of the crystal surface. Linear magnifications of one million times can readily be achieved.

In the accompanying photographs of the image of a tungsten crystal on the screen of the emission microscope, the effect of atoms adsorbed on the surface of the metal can be seen. Fig. 1 shows the clean surface of the metal. In Fig. 2 the surface is covered with positively charged atoms or ions. The individual bright spots represent groups of four to six ions which locally cause the electron emission to increase strongly. Figs. 3 and 4 show how increasing the temperature of the crystal surface causes the ions to reorientate themselves.

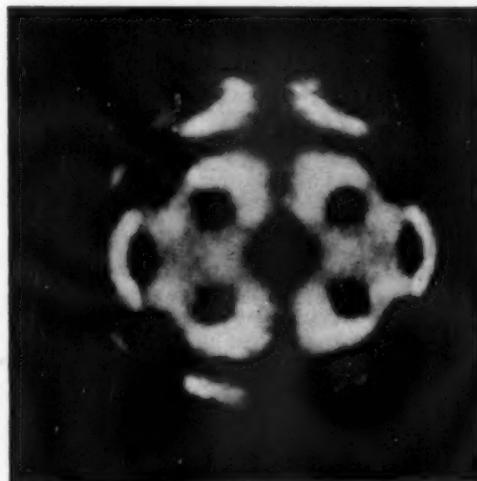
THE EMISSION MICROSCOPE

Adsorption of tungsten crystal made visible

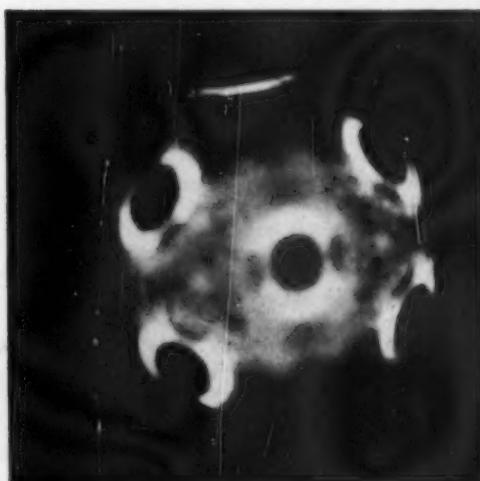
1 Image of a clean tungsten crystal



2 Surface covered with positive ions. The individual bright spots represent groups of 4 to 6 ions



3 Heating to 200°C. has led to a reorientation of the ions which have moved to places of highest energy gain



4 At a temperature of 450° the reorientation has progressed further

Fracture test for alloy steels

Notched bar fracture tests, such as the Charpy V-notch impact test, can be modified to simulate important characteristics of large spin bursting tests. Fracture toughnesses and appearances similar to those of large notched disks were obtained from specimens which were nitrided to produce a hard, brittle case. The method was described in 'Metal Progress,' July, 1960, by D. L. Newhouse and B. M. Wundi, supervisor, Forging Development, Materials and Processes Laboratory, and structural engineer, respectively, Large Steam Turbine Generator Department, General Electric Co., Schenectady, N.Y.

INVESTIGATORS of brittle fracture in large steel forgings have a big problem in reproducing the essential characteristics of such fracture in laboratory tests. These characteristics include a low nominal stress level and the virtual absence of fibrosity or ductility in the fracture. One solution to this problem is the use of bursting tests of large rotating notched disks. However, this method has drawbacks; it uses much material, is very expensive and therefore cannot be applied extensively.

Other tests also have limitations. For example, slow bend tests on large notched specimens (3 sq. in., 20% deep notch, 0.005-in. root radius) correlate well with bursting test results, but like the bursting tests, they required much metal. Of course, the standard Charpy V impact test has been very useful. Correlations have been found between fracture strength and large disks and the 50% Fracture Appearance Transition Temperature (FATT). However, because of the small size of the specimen and the large radius of the notch (in relation to other dimensions), the side shear lips and fibrous 'thumbnail' under the notch form a much larger proportion of the total fracture area than they do in large notch disk and slow bend test fractures. Because of this much greater boundary deformation (compared with large spin and bend tests), Charpy V specimens absorb too much energy. Therefore, they are not suitable for determining fracture toughness, G_{co} .

To fill this gap the authors have devised a new test to evaluate fracture toughness with small test specimens. Briefly, standard Charpy V impact specimens are treated by nitriding. This produces a very hard, brittle-behaving layer, completely around the circumferential boundary surface of the notched section. The temperature required for this method, 525°C., does not alter structure or properties of the Ni-Mo-V steel which was investigated.

The brittle boundary has two effects. First, it reduces drastically the impact energy absorbed (apparently at all temperatures) and, second, it raises considerably the brittle-to-ductile transition temperature as measured by either energy or fracture appearance criteria. Results of tests on a Ni-Mo-V forging showed that at 24°C. the energy absorbed was reduced from 30-6 ft.-lb., and the 50% FATT was increased by about 44°C. Also, the mode of fracture of the nitrided impact specimen in the transition range is radically altered. The fibrous 'thumbnail' under the notch is greatly suppressed, and the shear lips, which are usually observed on the free surfaces, are completely absent. The fracture, whether its appearance is crystalline or fibrous, is completely framed in the crystalline fracture of the nitrided case.

Interpretation

This drastic change in the fracture mode may be interpreted by assuming that the nitrided layer altered the boundary conditions for the fracture. Ordinarily, shearing deformation occurs at the unnotched surfaces. However, the thin and hard case results in a crystalline-appearing, brittle-behaving frame. It is as though the small (8 × 10 mm.) rectangular section of the standard Charpy V specimen were made a portion of a much larger section which exhibits a cleavage mode of fracture.

Probably, only those tests which exhibit largely crystalline fractures along with the energy values below 5-10 ft.-lb. for impact tests (or low maximum loads for slow bend tests) will be useful for estimating fracture toughness. This limitation is necessary because the definition of fracture toughness requires that the fracture, once started, be propagated by the release of elastic energy stored during the crack initiation period. The initiation process, on the other hand, must be facilitated. The test does this by proving that the brittle-behaving layer causes early formation and continuous enlargement of a fast-moving crack.

Estimates of fracture toughness, G_{co} , may be made from brittle-boundary impact energy data by dividing the energy expressed in in.-lb. by the area (in sq. in.) enclosed by the brittle case.

While these observations were made on a limited number of tests, the application of the 'brittle-boundary' principle offers much promise. Through this technique, impact values and the fracture appearance transition temperature can be obtained from nitrided Charpy tests. Such data can be used with considerable advantage in selecting fracture-resistant alloys.

Metallurgy in nuclear power technology

3. Properties of fissile and breeder metals

J. C. WRIGHT, B.Sc., Ph.D., A.I.M.

The metallurgy of nuclear power materials is developing on such a wide front and so rapidly that it is difficult for the non-specialist metallurgist to keep abreast with its scope. Dr. Wright, Reader in Industrial Metallurgy, College of Advanced Technology, Birmingham, outlines the subject in a series of articles which are appearing monthly in this journal

PHYSICAL PROPERTIES OF URANIUM. Clean uranium has a metallic lustre and is very dense (19.1 g./cm.^3). Its melting point, $1,130^\circ\text{C}.$, follows three allotropic forms of uranium in equilibrium at the temperatures given in Table 5.

The various allotropes have quite different properties; α -uranium is reasonably soft and plastic, particularly above $300^\circ\text{C}.$, and because of this many fabrication operations are best carried out at temperatures 300 – $650^\circ\text{C}.$ Although soft, the working properties of α -uranium are complicated by the directional properties resulting from the pronounced anisotropy of α -uranium. The β -phase is relatively brittle due to its complex crystallography, but the γ -phase is extremely soft; too soft for controlled and successful mechanical working under most conditions, although amenable to extrusion.

The α -uranium is strongly anisotropic, so many of its physical properties vary widely according to

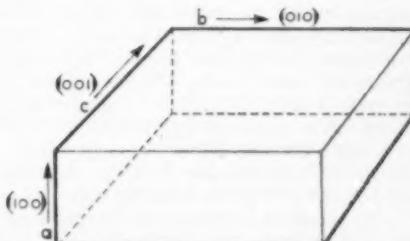
the orientation of the direction of testing in a single crystal, or the preferred orientation habit in a polycrystalline aggregate. This property is reflected in mechanical, electrical, thermal and optical properties. The mechanical properties are directional and vary with texture which is, in turn, very dependent on the fabrication and heat-treatment history of the metal.

Taking the thermal expansion properties as an example, the coefficients vary in the three crystallographic directions as follows (Fig. 12 and Table 6):

In a single crystal, thermal expansion and contraction can take place without restraint, but in the more normal polycrystalline uranium, such differential thermal expansion will create strain at the grain

TABLE 5 Allotropic forms of uranium

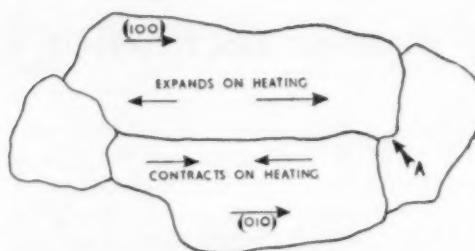
α -phase Up to $660^\circ\text{C}.$	β -phase 660 – $770^\circ\text{C}.$	γ -phase 770 – $1,130^\circ\text{C}.$
Base-centred orthorhombic crystallography	Tetragonal crystallography	Body-centred cubic structure
Crystal axes: $a \neq b \neq c$	Crystal axes: $a = b \neq c$	Crystal axes: $a = b = c$
4 atoms/unit cell	30 atoms/cell	2 atoms/cell



12 Orthorhombic arrangement

TABLE 6 Thermal expansion $\times 10^6/\text{ }^\circ\text{C}.$

Direction to axis	25–125 $^\circ\text{C}.$	25–325 $^\circ\text{C}.$	25–650 $^\circ\text{C}.$	
a (100)	Expansion
b (010)	Contraction
c (001)	Expansion
Volume coefficient	Expansion



13. Grain boundary stressing in thermal cycling. A shows boundary with differential stress on heating and cooling

boundaries, depending on the orientation of the axes of the various crystals (fig. 13).

Such grain boundary stresses may result in flow and deformation of the grains because the stresses can exceed the yield point. When this occurs, some of the deformation will not be recovered when the thermal cycle is reversed and the stress system with it. Thus it is possible to accumulate permanent deformation with thermal cycling. If the uranium has a pronounced crystalline directionality in the α -phase, and this may be difficult to avoid, the permanent damage due to thermal cycling also exhibits directionality. Heating and cooling effects are therefore not completely reversible and give rise to striking changes after a number of thermal cycles within the α -phase range. After 3,000 cycles of 50-550°C., it is possible to induce a bar of α -uranium to increase in length by a factor of between $\times 3$ and $\times 16$.

Thermal cycling effects on uranium

The dimensional changes on thermal cycling are functions of (a) rates of heating and cooling, (b) temperature level, (c) temperature range, (d) time at temperature, and (e) grain size and orientation. The greatest growth rates per thermal cycle are obtained with slow heating and fast cooling combined with a large temperature range of cycling. Little growth results if the upper temperature of the cycle is below 350°C.; above that temperature, the higher the temperature the shorter is the time for the growth rate to level off. After the first few cycles, which are usually not typical, the proportional increase in length per cycle in fine-grained highly-textured uranium specimens is in many cases constant for thousands of cycles. For large growths, after n cycles, $n \propto \log_e (L_n/L_0)$ where L_0 is the original and L_n the length after n cycles.

The highest growth rates occur in material with highly developed textures coupled with a small grain size. Material exhibiting no preferred orientation shows the least tendency to grow. Alloying elements in low concentration do not decrease the growth of α -uranium, in fact the growth may

be increased, presumably because of the smaller grain size.

Thermal cycling also results in microstructural changes; polygonization, development of porosity, crystallographic slip; roughening of grain boundaries and grain boundary migration may occur. In material of low purity, thermal cycling results in extensive formation of porosity. That the formation of porosity is not inherent in the mechanism is indicated by the fact that high-purity uranium shows no evidence of porosity, even though its rate of deformation is equivalent to that of the impure metal.

The amount of internal deformation is dependent upon the relative orientation of adjoining grains; where [010] directions are almost parallel, the internal deformation is at a minimum and increases with increasing spread between these directions. Random orientation increases the amount of internal microscopic deformation but these changes do not appear as over-all dimensional changes. Preferred orientation results in less internal microscopic deformation but gives unidirectional growth along the length of the specimen.

Most of the mechanisms that have been proposed to explain the dimensional and structural changes that occur in uranium when thermally cycled are based on intergranular stresses developed as a result of anisotropy in the thermal expansion of α -uranium. One proposed mechanism provides for a ratcheting condition to make the deformation non-reversible. This assumes grain boundary flow to relax the stresses at high temperatures, and crystallographic slip to relax the oppositely directed stresses at low temperatures. Another proposed mechanism suggests that continued elongation on thermal cycling depends on creep occurring in the stronger of adjacent grains at the high temperature part of the thermal cycle, and plastic deformation of the weaker grain in the low temperature part of the cycle.

Referring to fig. 13, these theories can be illustrated as follows:

1. If the metal is cooling, the lower grain expands in the horizontal direction because of its negative coefficient. The upper grain will tend to contract normally. If the grains do not slide over each other, the upper grain will tend to compress the lower. On subsequent heating, both grains will tend to expand horizontally; the upper one because of normal thermal expansion, the lower due to elastic after-effect (Bauschinger) of the compression. After the expansion due to elastic after-effect, the lower grain would normally tend to contract, but will continue to elongate because the Bauschinger effect makes it easy to stretch and finally it will tend to elongate because of increased plasticity at high temperatures. Thus the net effect in both grains

is horizontal expansion leading to permanent growth.

2. The thermal ratcheting effect assumes grain boundary sliding. On heating, the upper grain expands, the lower contracts and grain boundary sliding is assumed to take place. On cooling, the upper grain starts to contract, but as the temperature falls the grain boundary sliding becomes restricted and so the upper grain undergoes increasing tensile forces which are relieved by slip. Thus the upper grain does not shorten fully on cooling and yet lengthens fully on heating.

3. The deformation-by-creep explanation assumes no grain boundary sliding. On heating, the upper grain is expanding and tends to produce creep in the lower grain which lengthens. On cooling, the lower grain expands in any case, so an overall permanent expansion results.

4. Directional diffusion of interstitial atoms and vacancies has also been suggested as a mechanism of growth, but there are less grounds for assuming such a mechanism to operate under thermal cycling conditions than under irradiation conditions.

While mechanisms involving plastic deformation might be expected to elongate the grains, such elongation has not been observed. Differential grain sliding might be expected to create intergranular voids but these have not been observed. However, considerable grain boundary roughening has been observed.

Cast uranium has randomly oriented grains and, although the grain size will be large, the uranium will not exhibit gross macroscopic changes in dimensions after thermal cycling. Cold working, on the other hand, is likely to induce preferred orientation in the uranium and it will then be prone to growth. Another cause of growth, to be discussed later, is due to neutron irradiation of α -uranium. This again is induced in uranium with a preferred orientation. Avoidance of growth is largely dependent, therefore, on avoiding preferred orientation of coarse grains. In theory, there are two ways of producing stable, random, fine-grained uranium; by mechanical working and by a heat-treatment process, β -quenching.

Uranium produced by working in the α -stability range normally contains a high degree of preferred orientation. At temperatures approaching 300°C. there is a strong tendency for the [010] crystal axes to be oriented in the direction of working, but at a temperature near the α/β transformation temperature, the [010] texture is replaced during working by a texture in which the [100] direction tends to be dominant. Theoretically, it should be possible to find an intermediate temperature for working at which a fairly random orientation would result. In practice, however, it is not possible to control the temperature of a uranium bar sufficiently closely,

allowing for work-heat effects, machinery chilling effects and radiation heat losses, to guarantee a random grain distribution.

The more reliable method of producing a random structure is by β -quenching. When uranium is heated until thoroughly transformed to the β -phase and then quickly cooled through the α/β transformation, a randomly oriented fine-grained α -phase results. The rapid cooling tends to depress the temperature of the transformation below its equilibrium value, and the decreased facility for solid state diffusion at low temperatures prevents the free growth of large α -grains. Not only is the transformation temperature depressed but the mechanism of the β to α transformation is changed by very rapid quenching. Normally, it takes place by the processes of nucleation of the α -phase in the β -matrix, diffusion, and growth of the nuclei to α -grains. Rapid quenching gives rise to a diffusionless type of transformation in which the α -type lattice is formed from the β -phase by a mechanism of atomic lattice shearing. This produces an acicular type of α -uranium as opposed to the equilibrium equiaxed coarse grains.

The whole β -quenching mechanism is reminiscent of the production of martensite by quenching steels from the austenitic state. For very pure uranium, a very high rate of cooling would be required to depress the transformation temperature sufficiently to give random α -phase, just as in pure iron it is impossible to get martensite by the most rapid quench.

To refine the grain size of relatively heavy uranium sections, such as fuel-element bars, it is necessary to add an alloying element which will stabilize the β -phase or the γ -phase and thus bring about a delay in the beginning of the transformation to α . This gives more time to cool the whole of a moderately large cross-section without the premature transformation at high equilibrium temperatures. The influence of alloying elements on the transformation characteristics of uranium has been studied and time-temperature-transformation charts produced in a way very similar to the study of the effect of alloying elements in steels. Little difference in grain size results from either β or γ quenching and the time of soaking in the β or γ range has no effect on the resulting α -grain-size. The β -quench appears to be better for removing preferred orientation most completely.

Work hardening, recrystallization and grain growth

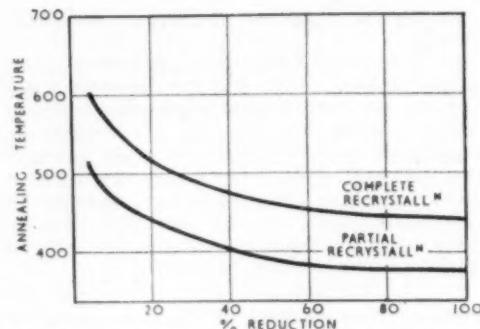
Recrystallization of uranium does not occur for specimens strained less than 1.2% at 640°C., and the critical strain at 625°C. is 1.6%. The recrystallization temperatures for larger reductions are outlined in fig. 14.

Most elements are nearly insoluble in α -uranium, i.e. very small amounts produce a second phase. Consequently, grain growth in uranium is extremely sensitive to differences in purity and to heat treatments that affect the dispersion of the second phase. If the inclusions are finely dispersed, they will have a much greater inhibiting effect on grain boundary movement than the same amount of material in relatively large inclusions. Small amounts of Al, Fe, Si have a grain refining effect.

The preferred orientation produced by working α -uranium, as mentioned above, considerably affects the mechanical properties which also become directional. The yield strength of uranium parallel to the rolling direction in as-rolled sheet after a considerable reduction can be of the order of 60 ton/sq. in., but at 45° to the rolling direction it may only be 45 ton/sq. in. In comparison, cast uranium would give about 25 ton/sq. in. with 4% elongation, but would not show directionality. Obviously, the ultimate tensile strength of uranium can be raised considerably by cold working and large differences exist in the properties of cast, wrought and annealed uranium (Table 7).

General properties

In general, uranium metal can be reasonably well rolled, forged, and drawn. It can be machined, using proper lubricants and coolants to prevent burning. The main fabrication problem is the chemical reactivity of uranium with the atmosphere, which makes casting, reheating and hot working of uranium rather difficult. Welding and brazing operations are impossible in a normal atmosphere and uranium has to be joined by these methods either *in vacuo* or under an inert gas shield. Not only is the reactivity of the atmosphere a problem; uranium is reactive in many other common media and hence its corrosion resistance is low. This can



14 Recrystallization temperature as a function of reduction of uranium plate

be improved by alloying, but it is more usual to employ cladding methods. The two most notable applications of such methods are the use of light alloy sheaths for uranium billet stock during mechanical working and the canning of fuel elements in the reactor.

Sheathing and cladding are important also, in that they prevent losses of pieces of uranium, and possibly fission products, which present a hazard from the standpoint of body radiation and toxic effects attending inhalation and ingestion of uranium and product debris. The toxicity of uranium is largely related to its high density and the danger of heavy metal poisoning.

Thermal conductivity

Heat is conducted in ordinary metals partly by free electrons and partly by vibrations of atoms or more complex components of the lattice.

In most metals, the electronic contribution is substantial. On heating such metals, interference with the electronic waves by increased vibration of

TABLE 7 Tensile properties of uranium at elevated temperatures

Condition	Test temperature, °C.	U.T.S., ton/sq. in.	Yield ton/sq. in.	Elongation, %
Rolled 300°C. + 12 h. at 600°C. + slow cool ..	R.T.	49.5	19.2	6.8
	300	15.6	7.8	49.0
	500	5.0	2.5	61.0
	R.T.	39.5	11.6	13.5
Rolled 600°C. + 12 h. at 600°C. + slow cool ..	300	14.3	8.5	43.0
	500	4.7	2.5	57.0

Typical mechanical properties of uranium

Treatment	U.T.S., ton/sq. in.	Yield strength, ton/sq. in.	Elongation, %
As cast ..	25.0	12.5	4.0
Rolled, 550°C. ..	43.0	13.8	11.0
Rolled 600°C. + 12 h. 600°C. slow cooled ..	39.5	11.6	13.5
Rolled 300°C. + 12 h. 600°C. slow cooled ..	49.6	19.4	6.8
Rolled 300°C. + 12 h. 700°C. slow cooled (β) ..	28.5	11.0	8.5

the atoms reduces thermal conductivity. It is, therefore, common for thermal conductivity to go down as temperature rises. The thermal conductivity of uranium increases with temperature. Many of the outer electrons of uranium atoms are believed to be involved in covalent bonds, so that electronic contribution to thermal conductivity is small and its decrease with temperature is small compared with the increase in thermal conductivity due to increases in the vibration of other components of the lattice. This accounts not only for the relatively low thermal conductivity of uranium but also for the positive temperature coefficient.

It appears reasonable that the thermal conductivities along each of the crystallographic axes of α -uranium should be different. Measurements on single crystals have not yet been made, but transverse and longitudinal measurements on highly oriented material do show differences in thermal conductivity.

Electrical conductivity

The electrical conductivity of uranium decreases with rise in temperature as in other metals. This conductivity is due solely to electronic conduction. The conductivity increases with upward phase changes because there are more conduction electrons and less co-valency.

ALLOYS OF URANIUM

In many respects, the properties of uranium render it unsuitable for use in the pure state for nuclear power production. Therefore, it is necessary to examine the alloy systems of other metals with uranium and the properties of promising materials in order to find improved substitutes for uranium, having the same fissionable properties but better physical properties.

Owing to the allotropic modifications existing in uranium and the varying solubilities among the elements in the various allotropic forms, uranium displays a variety of alloying mechanisms. The mechanisms fall into three general groups; systems showing some degree of solid solubility in one or more of the terminal phases; systems with limited solid solubility in terminal phases but forming intermetallic compounds; other systems not fitting either of the other criteria accurately and showing eutectics, monotectics and peritectics.

Solid solubility is not very extensive in either α - or β -uranium, but a few systems show moderate and even extended solubility in the γ -phase region. Typical of this latter type of system are uranium with molybdenum, zirconium or titanium. Intermetallic compound systems are provided by alloying with beryllium, carbon, iron and silicon for example; eutectics by vanadium and chromium; a

monotectic by magnesium, and peritectics by tantalum and tungsten.

Alloy theories for uranium take into account the structural effects and valency of three allotropes. Although uranium has six electrons that can contribute to its valency, α -uranium is partly co-valent and, like other transition metals, has electrons which tend to form covalent bonds and do not act as a whole number of electrons. α -uranium may be regarded as having a valency of 3.8 or about 4. As a consequence, the co-valent bonding plays a part in restricting α -solid solution in uranium, even though atomic sizes and valency of solute elements are favourable. Tetravalent Ti, Zr and Hf would be expected to stabilize alpha relative to beta uranium since β -uranium is thought to have a valency of about 5. The structure of β -uranium is unique and only very limited solid solubility is possible, particularly because its hard nature suggests some degree of non-metallic bonding. If β -uranium has an effective valency of 5, pentavalent elements such as V, Nb and Ta should stabilize β relative to α and γ . This is true with respect to α , but the crystal structure of γ is so much more favourable for solid solution that V, Nb, and Ta would probably not stabilize β with respect to γ . However, V, Nb, Cr and Mo are capable of retaining the β -phase during quenching if they are present in the correct amounts. γ -uranium is the most metallic state phase of uranium and is usually accredited with a valency of 6, or perhaps 5.8. With Zr, however, uranium behaves as though two of its electrons are donated to the Zr, and it seems to have a valency of 4.

In selecting an alloy for improved mechanical properties or corrosion resistance, the nuclear properties of the diluent element must be considered, in addition to considerations with regard to fabrication and other treatments. Dilution by alloying may possibly be an advantage in highly enriched fuels, but, in general, it is desirable that the diluent metal should have a low capture cross-section for neutrons. If the capture cross-section is high, the advantages of alloying may be overbalanced by a bad neutron economy. Because of their favourable thermal neutron capture cross-sections, aluminium, beryllium and zirconium have received considerable attention as potential diluents. For fast reactors the possible diluents are greater in number.

As examples of the effects of various alloying elements, the following are typical. The yield strength of uranium at 500°C. is increased by a factor of five by an addition of 2.2% Zr and by a factor of three with 0.4% Cr. A whole range of useful properties is provided by alloys which stabilize the γ -phase in uranium. This allows latitude in quenching to a martensitic α -structure which may be variously tempered. The tempering

must be controlled, particularly with respect to time, because it is possible to over-temper and lose the improved properties. For the same reason, long-term use at tempering temperatures in the reactor may also account for some reduction in properties. Systems typical of the martensitic α -quench type are uranium with molybdenum, niobium, titanium or zirconium. The greatest improvement in the corrosion resistance of high uranium alloys is found in the solid-solution type alloys. Titanium, zirconium, and niobium are examples of suitable alloying additions. The water corrosion resistance of uranium is greatly improved by molybdenum; 3-6% Nb; 2.5% Si; or 1.5-5% Nb + Zr.

In quenching uranium to achieve a fine random grain distribution, certain alloying elements reduce the as-quenched grain size at the same time as increasing hardness, ultimate tensile strength and yield point, with little change in ductility. The effect on grain size is most pronounced with additions of iron and silicon up to 0.02% and of aluminium up to 0.05%.

Alloying elements such as 1-3% Nb, Cr, Si or Mo have the effect of stabilizing the uranium against distortion, roughening and cracking, as it is thermally cycled through the α/β -phase transformation boundary at 660°C. One of the reasons that unalloyed uranium is restricted in reactor use to temperatures below 660°C. is because of the distortion caused by the α/β -phase transformation.

Transformation kinetics in uranium alloys

All uranium-alloy systems which have been studied have shown the alloying component to be more soluble in the γ , B.C.C., phase than in the α or β phases. In general, when a high-temperature phase is quenched to below the transformation temperature, a metastable supersaturated solid solution results. Temperature-time-transformation curves have been produced for some systems and several heat treatments based on them.

1 *Interrupted quenching* The specimen is held at a temperature in the β or γ range, long enough to bring about an equilibrium structure, then is quenched to a lower temperature and held at that temperature for a controlled time. This is followed by a further quench to room temperature either before, during or after transformation to the lower-temperature phase. This treatment is comparable to the isothermal heat treatments on steels.

2 *Quench and temper treatments* The specimen is heated in the γ - or β -range long enough to give an equilibrium structure, then is rapidly quenched to a temperature usually below 100°C. The γ - or β -phase may be retained or may undergo a diffusionless transformation during the quench depending on the nature and amount of alloying elements.

In either case the structure is metastable and transforms on tempering.

3 *Continuous cooling treatments* The specimen is cooled from equilibrium in the β or γ states, to room temperature at a chosen cooling rate without interruption.

As an example of the time-temperature-transformation curves, those for uranium with 0.3, 0.6, 1.8 and 4% Cr are given (figs. 15 a-d).

The existence of two C's in the curves for lower chromium contents indicates that there are two transformation mechanisms. It is speculated that the higher temperature mechanism is controlled by rate of diffusion of Cr in β -U, while the lower mechanism is diffusionless.

Alloys containing less than 1% Cr may remain in the β -state at room temperature when quenched in cold water from 720°C., but transform progressively to α -uranium over a period of several days. Quenched alloys with more than 1% Cr may remain in the β -condition provided they are not heated or deformed. The β -phase of this composition is so delicately energy sensitive that a scratch by a steel instrument may cause needles of α to form along the [321] planes of the β -structure, if the alloy does not transform completely to α . The product of such a low-temperature transformation will be acicular, martensitic α . With increasing % Cr, the lower C's of the transformation diagrams tend to disappear and the mechanism of transformation becomes predominantly one of diffusion. With decreasing chromium content, the upper C's tend to disappear and the transformation is predominantly diffusionless.

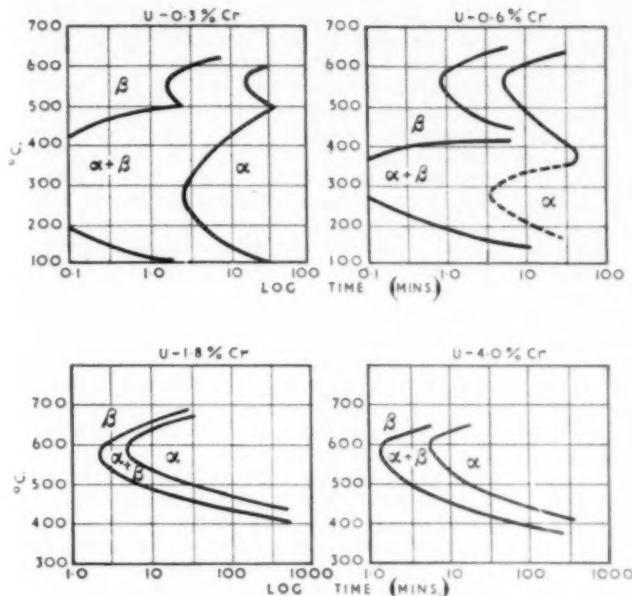
Transformation diagrams for high molybdenum (10-15% by wt.) alloys of uranium indicate that the γ -U/Mo alloy transforms by nucleation and growth so slowly that it is possible to quench the alloy and retain γ -phase at room temperature.

The U-Zr, U-Nb and U-Nb-Zr systems behave in much the same way as the U-Mo system. However, in these systems the γ -phase field exhibits 100% continuous solid solubility, and they have important corrosion-resistance applications.

The possibilities of isothermal heat-treatments of uranium alloys based on binary and ternary systems involving aluminium, chromium, iron, molybdenum, niobium, silicon, titanium, vanadium and zirconium have been investigated.

Metallography of uranium

Uranium is rather more difficult to prepare for microscopical examination than most metals. Since it is relatively soft it is difficult to remove the surface layer of distorted metal in polishing without producing further distortion. Rough polishing and dragging are likely to produce twinning deformation on and near the prepared surface. At the same time



15 a-d TTT curves for uranium-chromium

it is difficult to retain inclusions. Uranium alloys being generally harder are more amenable to preparation, but considerable care is required.

The technique used is wet grinding followed by diamond paste polishing and finally electropolishing, after which the specimen is normally suitable for direct examination without etching. An anodic polish in a solution such as 1% solid citric acid, $3\frac{1}{2}$ conc. HNO_3 in distilled water, for about 12 minutes with a current density of 15-30 milliamps/cm.² at room temperature is suitable for grain boundary and twin band discrimination without removal of inclusions. Inclusions are more readily studied after a shorter polishing time. Another useful solution is 30% phosphoric acid, 30% ethylene glycol and 40% alcohol, all by volume, used under the same conditions as above. Normal dip etching of uranium specimens is not very satisfactory, but most of them are amenable to cathodic electrolytic etching which generally avoids pitting and staining. Uranium may also be thermally etched, particularly for grain boundary relief, by heating an electropolished specimen in a vacuum at a temperature in excess of 700°C. for a few minutes.

Because of the anisotropy of α - and β -uranium phases, it is possible to examine specimens readily under polarized light, but even with this aid the grain size and structure of uranium are difficult to interpret, particularly in cast uranium. The micro-

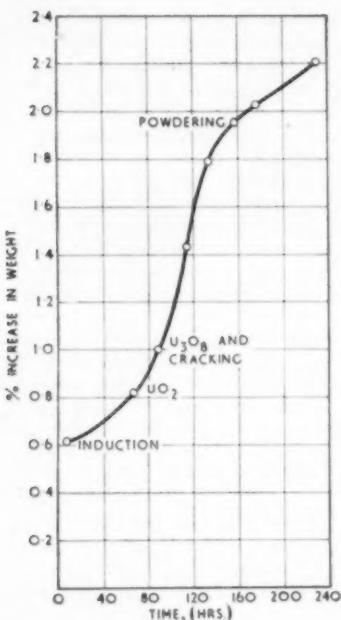
structure is much more clearly defined in specimens recrystallized by annealing after cold work.

Oxidation properties of uranium

It has already been pointed out that uranium itself has a rather poor corrosion resistance.

Considering the oxidation of uranium, there are several oxides which may be formed. Examples are UO_2 , UO_3 , U_2O_5 . If the lattice characteristics of the oxide and the metal are similar, the oxide ions will tend to conform to the lattice of the metal. This is known as epitaxy. The degree of misfit in the parameters of the metal and the oxide should be within 15%. The α -phase of uranium is orthorhombic ($a = 2.85$, $b = 5.86$, $c = 4.94 \text{ \AA}$) but only one of the oxides has an orthorhombic structure; U_2O_5 - U_2O_8 ($a = 8.27$ - 6.70 , $b = 31.65$ - 11.94 , $c = 6.72$ - 4.14 \AA) and obviously the parameters involved are not within 15% of the metal parameters. UO_2 is cubic (F.C.C.) with a parameter of 5.46 \AA , decreasing to 5.30 \AA as the composition tends to $\text{UO}_{2.3}$. UO_3 is hexagonal with $a = 3.963$ and $c = 4.160 \text{ \AA}$. One would not therefore expect epitaxy of oxide on uranium.

In oxidizing any metal, it is assumed that metal ions diffuse out through the oxide film and oxygen ions diffuse inwards to the metal/oxide interface. In uranium, U^{4+} is a large, highly charged ion and would not be expected to diffuse readily through the oxide film. Thus oxidation occurs mainly by the



16 Percentage increase in weight with time for uranium in air at 200°C. (T. Wathen, 'Corrosion of uranium metal in air and steam at various temperatures' BR-223A 1943)

ionic diffusion of oxygen ions, O^{2-} . Although the uranium ions will have a much lower tendency to diffuse in the oxide than oxygen ions, diffusion in the oxide is still fairly easy, making the oxide less protective. UO_2 , for example, has a composition range of UO_2 – $UO_{2.3}$. This, together with the fact that the lattice shrinks but increases in density as the oxygen-to-uranium ratio increases, suggests that it possesses a lattice which includes interstitial oxygen ions rather than a deficiency of uranium atoms. The excess interstitial ions, whether positive or negative, will cause vacancies so that electrical neutrality is maintained. It is the presence of such vacancies that markedly enhances diffusion rates, and oxidation rates, in uranium oxide. The squeeze energy necessary for migration of oxygen ions through the oxide can be increased, and therefore oxidation rate decreased, by contracting the lattice. This can be done by adding a substitutional alloying element whose ionic diameter is smaller than that of the ion it replaces. This appears to be the mechanism when zirconium is added to uranium.

UO_2 forms in air below 100°C., $UO_2 + U_3O_8$ at 100–200°C., and U_3O_8 at higher temperatures, when the oxide almost invariably powders (fig. 16). UO_3 begins to form above 350°C. but will not form

completely at normal atmospheric pressure. This is the situation in dry air. When moisture is present corrosion is generally accelerated. Some of the moisture absorbed on the oxide ionizes to form OH^- and H^+ . There is some tendency for the OH^- ion to react directly with the oxide to form oxide hydrates. The H^+ ion is small and diffuses readily through the oxide lattice, when a hydride can be formed or hydrogen released as a gas. In either case the protective oxide film is disrupted and allows further oxidation. When the uranium lattice is contracted, as when zirconium is added as an alloying element, the diffusion of hydrogen is reduced. Thus the uranium tends to form oxides rather than hydroxides or hydrides. In this way an alloying element such as zirconium improves both gaseous and wet corrosion: 5% of zirconium by weight added to uranium provides a highly protective oxide film, even when there is only a small concentration of oxygen available.

Since the corrosion resistance of uranium (and, for that matter, plutonium and thorium also) out of the reactor is not good, and it can be assumed that inside a working reactor it will be worse, it is necessary to protect the uranium from corrosive environments. This is one of the functions of canning materials.

PLUTONIUM

Production of plutonium

The concentration of plutonium in minerals such as pitchblende is no more than one part in 10^{11} it is clear that there is no naturally occurring plutonium ore. Any plutonium must therefore be produced from U_{238} by irradiation in a reactor. The yield and purity of the plutonium will depend on the type of fuel element, the design of the reactor, the extent of irradiation and the chemical processes used to separate the plutonium from the rest of the fuel element materials. The irradiation extent decides which of the plutonium isotopes are likely to predominate in the mixture produced. If plutonium is irradiated in the reactor it tends to capture further neutrons. Thus fissile Pu_{239} may progress to Pu_{240} which is non-fissile and even further with extended irradiation to Pu_{241} which is again fissile. Plutonium extracted from fuel rods that have spent anything up to five years in a power reactor would therefore consist of a mixture of isotopes, some fissile and some not. This might be satisfactory as a fuel, but is not suitable for military purposes without further processing.

It has been estimated that about one ton of plutonium will result from each 1,500 MW atomic power from gas-cooled reactors. In current designs, fuel elements can be removed from power reactors for processing, if necessary, at short intervals and in this way the maximum amount of

Pu_{239} can be recovered, for instance, for military purposes. In this way the Pu_{239} yield per MW. would be increased, but only at the expense of some power-producing efficiency.

If plutonium is irradiated sufficiently to produce the heavier isotopes the plutonium mixture becomes γ -active as well as α -active. This complicates the handling problems, since operators must then be protected against γ -radiation during processing. This will involve concrete shielding and remote-control operations instead of the glove-box type of protection which is adequate against α -active plutonium. However, it is not anticipated that these handling difficulties will be a serious impediment to the use of plutonium as a reactor fuel.

The extraction of plutonium from fuel elements after irradiation in a reactor has many similarities in principle with the extraction of uranium from its ores. In the initial stages, the aqueous-organic solvent method of extraction can be used, followed by precipitation before conversion to the metal or the oxide. Reductions to the metal have been made by bomb reduction and by electrolysis from a fused salt bath. The stability of plutonium oxide and of the halides is comparable with that of the corresponding uranium compounds.

Physical properties of plutonium

Plutonium is more complex than uranium in its properties and handling difficulties. It exists in six different allotropic forms with transformations roughly every 100°C. from 126–484°C., the precise temperatures depending on rates of heating and cooling. These allotropes, some of which have very complex structures, vary considerably in density from a figure of about 19.8 g./cm.³ for α -Pu to 15.9 g./cm.³ for δ -Pu. Some of the properties are given in Table 8. The various densities, coupled with a variation in the coefficients of thermal expansion of the phases, lead to severe dimensionable changes and deformation after thermal cycling.

TABLE 8 Some properties of the various phases of plutonium metal

Phase	Approximate temperature of transformation, °C.	Crystal structure	Density, g./cm. ³	Approximate coefficient of expansion, $\times 10^6/^\circ\text{C.}$
Alpha	120	Monoclinic	19.8	+56
Beta	210	Body-centred monoclinic	17.9	+42
Gamma	312	Orthorhombic	17.1	+35
Delta	450	Face-centred cubic	15.9	- 8.6
Delta prime	475	Body-centred tetragonal	16.0	- 16*
Epsilon		Body-centred cubic	16.5	+36.5

* The value quoted for the coefficient of expansion of delta prime is very doubtful. Far greater negative coefficients have been reported for this phase.

The high positive thermal expansion of α -Pu and the negative thermal expansions of the delta and delta prime phases, which are as yet unexplained, are unequalled by any other metal. The delta prime phase transformation is not detected as separate from the delta transformation except in high-purity plutonium. For instance, 0.1% silicon suppresses the delta prime phase completely, but titanium, on the other hand, has a stabilizing effect. Polonium, which is simple cubic in structure, has also been reported as having a negative coefficient of thermal expansion. The kinetics of all the plutonium transformations are very sensitive to prior treatment and to the presence of impurities. When plutonium metal is not of high purity, considerable dilation hysteresis occurs on heating and cooling. The effect of impurities is generally to make the transformations more sluggish.

The transformation temperatures of plutonium found by dilatometry, magnetic susceptibility and by differential thermal analysis agree reasonably well. The δ - δ' heat effect is the smallest and in many plutonium alloys this transformation appears to be suppressed.

The electrical resistance of plutonium is very high compared with other fully metallic elements. It is over 100 microhm-cm. in all phases and about 150 microhm-cm. in α -Pu. Its temperature coefficient of resistivity is negative except in the δ - and δ' -phases. Thus, in this respect, it differs from uranium and exhibits properties similar to a semi-conductor.

Alloys of plutonium

The constitution diagrams of plutonium alloys are characterized by the various allotropic forms of plutonium and a tendency towards inter-metallic compound formation rather than extended solid solution.

Simple eutectic systems with negligible solid solubility are provided by Pu-V and Pu-Cr, the eutectic temperatures being 625 and 615°C. res-

TABLE 9 *Impurities in thorium from various sources*

Material	Chemical composition							
	C	O	N	Al	Si	Fe	Be	H
Ca + $ZnCl_2$ reduction ..	370	120	150	90	90	140	30	100
Iodide Th	200	110	10	Trace	Trace	Trace	100	100
U.S.A. Ca-reduced Th ..	500-1,000	200-1,300	100-200	100		250-350		50-150
Electrolytic Th U.S.S.R.			30-100			240-600	30	2,000-4,000
Crucible-melted Th ..		70-80	20-30					1-1.5

pectively. The Pu-Mn system is a double eutectic system separated by one intermetallic compound $PuMn_3$, and again exhibits no solid solubility. The Pu-Fe system contains Pu_6Fe and $PuFe_2$ compounds. The Pu-Ni system contains at least six intermetallic compounds $PuNi_x$, where $x = 1-5$ and Pu_2Ni_{17} . Limited solid solubility in some phases of the Pu-U system is accompanied by two intermetallic compounds, PuU and Pu_3U , ζ and η . This means that fuel elements containing a significant quantity of plutonium for thermal reactor operation can have an α -structure. The composition of plutonium hydride is variable from PuH_2 to $PuH_{2.7}$ or PuH_3 . The oxides of plutonium include PuO , Pu_2O_5 , Pu_4O_7 , PuO_2 . There are two carbides, PuC and Pu_2C_3 , one nitride— PuN . Several plutonium-aluminium compounds, $PuAl$, $PuAl_2$, $PuAl_3$ and $PuAl_4$, can be formed. Plutonium forms compounds with some low-melting-point metals, magnesium, tin, indium, bismuth, mercury and lead. Usefully high solid solubility of plutonium is achieved in zirconium, thorium and uranium.

Generally speaking many of the plutonium alloys are simpler than the corresponding uranium alloys.

Handling

Critical masses of solid plutonium are small in critical geometries, amounting to a few pounds only. This limits the quantity which may be fabricated at one time.

Pu_{239} is a short-range alpha-particle emitter so that ingested plutonium dissipates much of its irradiation energy very locally in the tissues immediately surrounding the deposit. Plutonium metal generally contains isotopes in addition to Pu_{239} and consequently emits low-energy gamma and X-ray radiation in addition to alpha.

Rubber gloves are used as a minimum precaution when handling plutonium and most work is carried out in glove-boxes with an atmosphere slightly below normal pressure to minimize outleakage.

The atmosphere may be inert argon or helium. Some plutonium-light metal combinations produce neutrons and further precautions are necessary.

Remote handling and heavy shielding becomes necessary when plutonium metal is appreciably gamma active.

Apart from the radiation hazards, plutonium is also capable of initiating heavy metal poisoning, but compared with other hazards this is only of academic interest.

Within the limits imposed by the hazards of plutonium, the metal may be vacuum-melted and cast, arc-melted, rolled, extruded, and processed by powder methods, the latter being particularly useful for production of cermets and ceramics.

THORIUM

Properties of thorium

Thorium is metallic in appearance, about as dense as lead and fairly soft. Compared with uranium and plutonium, thorium has a much simpler crystal structure. It is face-centred cubic up to $1,400^{\circ}\text{C}$. and body-centred cubic from $1,400-1,750^{\circ}\text{C}$., the melting point. The density of thorium is 11.72 g./cm.^3 calculated from its X-ray parameters, but in production it is $11.5-11.66 \text{ g./cm.}^3$. The thermal coefficient of expansion of thorium is not as large as uranium, being $11.0-12.5 \times 10^{-6}/^{\circ}\text{C.}$, and since the crystal structure is cubic it is not surprising that the coefficient of expansion is not direction dependent.

Cold-rolled thorium exhibits a certain amount of preferred orientation, as also does the extruded product, but annealing removes most of the directionality.

The properties of thorium depend on the impurities it contains and these are frequently dependent on the method of preparing the thorium (Table 9). For instance, calcium-reduced thorium may contain 0.001% calcium but little fluorine and chlorine, whereas electrolytic thorium may contain

0.003% fluorine and negligible calcium. Arc-refined iodide thorium is of the highest purity. Carbon produces a gradual but significant increase in hardness of thorium and several other elements actually lower the hardness of thorium containing small amounts of carbon, probably because they react with the carbon in some way and reduce its potential hardening effect.

Because the properties depend on the history of each particular batch of thorium, it is not advisable to quote accurate figures for the mechanical properties. However, the tensile strength of thorium lies in the range 10-18 ton/sq. in. at room temperature, the yield strength (0.2% proof stress) 5-13 ton/sq. in. The yield strength is particularly sensitive to carbon content and increases sharply with increasing carbon content; whereas under the same conditions the impact strength decreases. The yield strength is also sensitive to the degree of cold working the thorium has undergone. In fact a 25% reduction in area increases the U.T.S. by 30-40% and the yield strength by 100%. Further cold reductions have far less effect.

Alloying

Thorium reacts with air, nitrogen and hydrogen at all temperatures above normal, and several liquid media also attack it. Bismuth, gallium, lead and lead-uranium react extensively with thorium, but lithium, sodium, and sodium-potassium coolants are virtually harmless. However, the sodium-potassium must be oxygen-free or oxidation of the thorium will result.

Most alloying elements, when added to thorium, exert a deleterious effect or only impart a slight improvement in corrosion resistance of thorium. Thorium-zirconium alloys, however, exhibit good corrosion resistance to water at 100°C. With the exception of zirconium, most alloying elements when added to thorium exert a deleterious effect or at best impart only slight improvement to the high-temperature water corrosion resistance of thorium. The reaction of thorium with water vapour results in oxidation with release of hydrogen which, in turn, may form a hydride. Hydrogen reacts extensively with thorium at relatively low temperatures, forming a hydride which is not very compact and eventually disintegrates.

The atomic diameter of thorium is relatively large and this has considerable bearing on the types of alloy systems produced. In the face-centred-cubic form, thorium has an atomic diameter of 3.59 Å, and in the body-centred-cubic form (above 1,400°C.) of 3.56 Å. Only a few metals lie in the size range within 15% of these figures and are thus possible contributors to a solid-solution type of alloying. The metals that are within the range include magnesium, zirconium, hafnium, cerium,

lanthanum, lead, bismuth and antimony. Since thorium is markedly electropositive and the possible solutes are limited, it is to be expected that thorium alloy systems will be characterized by intermetallic compounds rather than extensive solid solutions.

Handling

In handling thorium, its alloys and compounds, certain precautions are necessary, due to possible radiological toxicity, chemical toxicity and the risk of spontaneous ignition or explosion, particularly with finely divided thorium. Chemical poisoning might arise from inhalation, ingestion or incision pick-up of thorium. The radiological toxicity arises from α - or γ -radiations from either the element or its decay products.

Uranium-platinum alloys

concluded from following page

containing dissolved platinum. $U\text{Pt}_5$ converts to $U\text{Pt}_3$ and a liquid above 1,460°C.

In the experiments it was apparent that platinum dissolves in solid uranium and that uranium can be dissolved in solid platinum. Up to 5 at.-% platinum can be held in the body-centred cubic lattice of gamma-uranium; however, this dissolved platinum lowers the gamma-uranium transformation to the monoclinic beta-uranium lattice from 762-705°C. Similarly, the beta-uranium will hold a maximum of only 2.35 at.-% platinum, which lowers the transformation to the orthorhombic alpha-uranium lattice from 660-589°C. The maximum amount of platinum dissolved in alpha-uranium is slightly less than 1.2 at.-%, the smallest amount for the three phases of uranium. In contrast to this behaviour, the amount of uranium that dissolves in platinum is fairly constant with temperature change reaching a maximum of 4.5 at.-% at 1,345°C. and decreasing to 4.0 at.-% at room temperature.

Cooling point curves obtained with an electronic recorder demonstrate the effect of alloying on melting points. The addition of 12 at.-% platinum to uranium lowers the melting point of uranium by more than 100°C., from 1,131-1,005°C. Even more drastic is the effect of uranium on platinum's melting point, which decreases from 1,760°C. for the unalloyed metal to 1,345°C. when 12.5 at.-% uranium is added. Between two eutectics which occur at 1,005° and 1,345°C. is the maximum melting point (1,700°C.) of the $U\text{Pt}_3$ compound.

Hardness measurements obtained for the different compounds were converted to diamond pyramid hardness, kg./mm.². The values thus derived were: $U\text{Pt}_5$, 385; $U\text{Pt}_3$, 905; $U\text{Pt}_3$, 405 and $U\text{Pt}_3$, 610. Hardness values for uranium and platinum in solid solution are, respectively, 425 and 250.

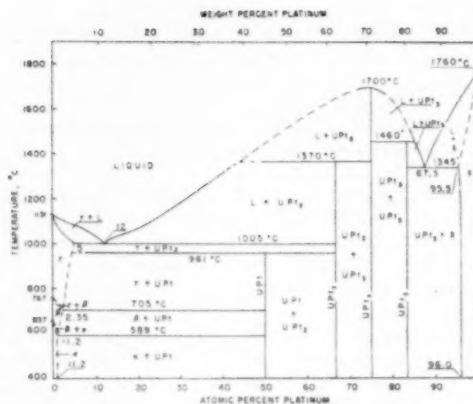
Uranium-platinum alloys

TO PROVIDE INFORMATION on the alloying behaviour of uranium, a study of the uranium-platinum system has recently been completed at the U.S. National Bureau of Standards, in a programme sponsored by the U.S. Atomic Energy Commission. The present study is the first work in an extensive programme to establish the binary phase relationships between uranium and the six platinum metals.

In order to construct a phase diagram of the two metals, J. J. Park and D. P. Fickle of the Bureau's chemical metallurgy laboratory correlated data from thermal and metallographic analyses, and X-ray diffraction studies.* The diagram shows that the system is characterized by four intermetallic compounds: $U\text{Pt}$, $U\text{Pt}_2$, $U\text{Pt}_3$ and $U\text{Pt}_5$. Each compound has a different hardness and melting point. These findings, while important to the development of atomic power, may have other applications, since some of the materials decompose at relatively high temperatures.

For the experiments, alloys varying in composition were prepared from 99.9% pure uranium and 99.5% pure platinum sponge. The sponge was compressed into small pellets before melting. Sixteen alloys with a composition ranging from 0-45 atomic% platinum were induction-melted under vacuum, and 20 alloys having 45-99.5 at.-% platinum were prepared by arc melting under an atmosphere of helium.

To obtain the thermal analysis data, a molybdenum-wound resistance furnace was employed for specimens with liquidus temperatures up to



1 Phase diagram for the uranium-platinum system (U.S. National Bureau of Standards)

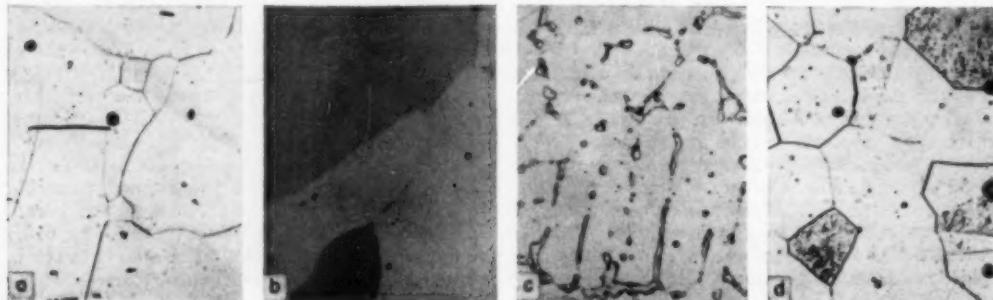
1,400°C.; for those whose liquidus temperatures were higher, an induction furnace was used. The specimens prepared for metallographic examination and X-ray diffraction analysis were mounted in bakelite and finished by electrolytic polishing. Micro-hardness tests were made to assist in identifying the constituents of the various alloys in the uranium-platinum system.

The combined data show that the $U\text{Pt}_3$ compound has a melting point of 1,700°C. and passes directly from solid to liquid. This reaction contrasts sharply with those found for the remaining three compounds which pass from the single solid-state phase to a heterogeneous mixture when heated above decomposition temperatures. The $U\text{Pt}_2$ compound is solid up to 1,370°C., but at higher temperatures it becomes a mixture of the $U\text{Pt}_3$ compound and a liquid. The $U\text{Pt}$ compound decomposes about 961°C.; the solid decomposition products are $U\text{Pt}_2$ and gamma-uranium phase

concluded on previous page

* 'Uranium-platinum system,' by J. J. Park and D. P. Fickle, *J. Research NBS*, 1960, **64A**, 107.

2 Typical structures of uranium-platinum alloys. (a) $U\text{Pt}_1$, phase 66.7 at.-% Pt ($\times 100$). (b) $U\text{Pt}_3$, phase 74.6 at.-% Pt ($\times 500$). (c) $U\text{Pt}_5$ phase in matrix of $U\text{Pt}_3$, 82.8 at.-% Pt ($\times 500$). (d) Alloy of 96.4 at.-% Pt, terminal solid solution ($\times 250$)



NEWS

Stress-relieving by radiant electric heating

RADIANT ELECTRIC HEATING for stress-relieving a large welded-steel structure has been successfully applied at the Erith Engineering Works of the General Electric Co. Ltd. to a bottom-half turbine exhaust casing of a 200-MW. turbo-generator. G.E.C. is manufacturing two of these 200 MW. machines for extensions to the Kincardine Generating Station of the South of Scotland Electricity Board.

It was decided to fabricate the two bottom-half turbine exhaust casings for each of these machines as complete units and carry out the stress-relieving by electric heating. This was a departure from normal G.E.C. practice on large reheat turbo-generators. The exhaust casings have previously been made in sections which were stress-relieved in conventional furnaces before being bolted together to form a complete component. Each of the Kincardine casings is 47 tons in weight with overall dimensions of 21 ft. 3 in. \times 17 ft. \times 8 ft. 3 in. high.

Due to the amount of metal and the complicated nature of the structure, calculations showed that it was necessary to use 68 single-phase radiant heating elements each of 7½ kW. rating. The positions of the heaters within the casing were carefully arranged to ensure even heating throughout the structure, and each heater could be individually controlled.

The casing was placed on a firebrick base and most of the heating elements were suspended vertically inside, although a number were floor-mounted at predetermined strategic points. After covering the open top with a $\frac{1}{2}$ -in. steel plate, the whole structure was encased in thermal insulation to a depth of 6 in. Forty-two thermocouples disposed about the casing were connected to seven 6-point graphic recorders for temperature measurements. It was thus possible to record average conditions in the whole casing during the heating operation and individual heaters were switched to maintain uniform heating.

When the temperature reached 650°C. the power input was reduced to keep the temperature constant while the casing 'soaked' for 3 h. At the end of this period the heaters were switched off and the casing was allowed to cool to ambient temperature.



Wiring up the radiant electric elements used to stress-relieve a bottom-half turbine exhaust casing of the 200 MW. set for Kincardine generating station. G.E.C. is manufacturing two such sets for the South of Scotland Electricity Board. The stress-relieving was carried out at the Erith Engineering Works of the Company.
(Photograph courtesy G.E.C.)

Steel tube mill order for Head Wrightson

The Head Wrightson Machine Co. Ltd., of Middlesbrough, a subsidiary of Head Wrightson & Co. Ltd., have been awarded a contract for a complete seamless tube mill by Tubes Ltd., Desford, near Leicester, a member of the Tube Investments Group. This order, which is valued at approximately £800,000, follows a previous order for a similar mill.

The seamless tube mill consists of specialized equipment for producing hot finished alloy steel tubes between 1½ and 6 in. o.d. to very close tolerances. The tubes will chiefly be made in those grades of steel used for the production of ball and roller bearing races, but the mill is also equally suitable for making medium- and thick-walled tubing in low or high-carbon steels for a variety of other purposes where accuracy is important.

The mill equipment consists essentially of a billet piercer, a three-roll cross rolling mill or elongator, an 11-stand tube reducer and a rotary sizer.

Polishing stainless steel

The Electropol process of Electropol Processing Ltd. for stainless steels is an electrochemical process which produces a finished, polished surface, which is bright, clean and highly resistant to corrosion and surface adhesion. It is faster and more economical than former mechanical polishing methods. The surface is also less resistant to corrosion, because any inclusions introduced during the rolling, fabrication or manipulation processes are removed from the surface and do not form seats for corrosion.

The stainless-steel article is immersed in a chemical bath and an electric current passed through. A controlled amount of metal is removed from the surface in such a way that the minute ridges, together with process films, are removed and a bright, smooth surface obtained. The thickness of the metal removed is usually less than half of one-thousandth of an inch.

There is no limit to the size of the article to be electro-polished. Large, completely fabricated tanks can be electropolished *in situ*, thus ensuring that the welds are also electropolished.

INSTRUMENTATION

Mechanical surface-roughness comparator

Although there are several high-precision surface-roughness measuring instruments on the market, there is a great need for an instrument which is simple and inexpensive enough to be used in the workshop, and the Rubert surface-roughness comparator has been designed to fill this need.

The assessment of surface roughness by means of tactile comparison with calibrated roughness scales has become a normal practice in engineering. Although the standard comparison scales used are calibrated and measured with electronic stylus instruments (Talysurf, Perth-O-Meter, etc.) based on purely geometrical definitions (CLA, maximal depth, etc.), the assessment by tactile comparison is based on purely functional, mainly frictional qualities. The fact that tactile comparison has proved its usefulness in assessment of numerical values therefore is a proof of a close relationship between the various national standards (in Britain CLA, on the Continent mainly maximal depth) and frictional qualities.

The Rubert surface roughness comparator is based on measurement of the friction coefficient of machined surfaces and can be calibrated in CLA or in other standards with sufficiently high accuracy to be used in machine shops. It represents a new departure from conventional methods and can be considered as a mechanized finger-nail with a consistent and repeatable meter reading.

The measuring unit consists of a sensing head in the form of pivoted wheel made of special alloy connected to a dial indicator and retained in the zero position by a spring.

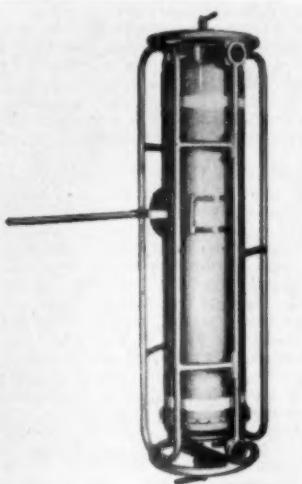
To assess the finish on any particular surface the sensing wheel is moved repeatedly to and fro across the surface. The friction between the surface and the sensing wheel will cause the wheel to rotate, moving the pointer over the scale and tensioning the spring until such time as the spring tension balances the frictional drag and the wheel ceases to rotate. The indicator reading is retained by a ratchet and pawl and the surface finish can be read directly from the dial which can be calibrated in either CLA or maximal depth. Before taking another reading the pawl must be released by slight finger pressure, which will reset the indicator to zero.

Portable X-ray unit

A new lightweight, portable, industrial X-ray unit of 300 kV. capacity, known as the Baltospot G300D, has been introduced by Pantak Ltd., of Vale Road, Windsor, Berks., for examination of mild steel of up to 3-in. thickness (fig. 1).

Both insulation and cooling of the X-ray tube in this unit is effected by a chemically and physiologically inert and non-inflammable gas. The use of this medium results in a lightweight tank head construction and achieves a high power weight ratio, the weight being 142 lb. and the capacity being 300 kV. The unit can be supplied with either a conventional 40-deg. solid angle beam insert tube with a fine focus, size 3.0 mm., or a 360-deg. circumferential radiation insert tube. Cooling of the anode is achieved in either case by forced circulation of the insulating gas by means of an internal blower.

The tank head, which is cylindrical in shape, is pressurized and is fitted with a pressure gauge so that the



1 G300D
portable
X-ray unit

insulating gas may be checked at any time. A cradle is supplied in which are incorporated anti-shock mountings. The tube is protected against excessive temperature by a thermo switch mounted in the tank head. A further device in the control unit simulates the thermal capacity of the anode and gives the operator a visual indication of overheating. A particular advantage is that a series of exposures can be planned without risk of overheating the tube. The maximum dimensions are 40 in. long \times 9 in. dia. When fitted with the protective cradle the weight is increased from 142 lb. to 171 lb. The control unit is of the carrying case type, the maximum dimensions being 18 in. long \times 14 in. wide \times 8 in. deep. The weight is 60 lb.

Cold-cathode-type discharge vacuum gauge

A new, cold-cathode-type discharge gauge for the accurate and uniform measurement of high vacuum has been introduced by F. J. Stokes Corporation, Philadelphia. The gauge, model DG-10, combines the accuracy and dependability of ionization-type gauges with construction features that make it compact and flexible in application. It has a wide range—from 10^{-1} – 10^{-6} mm. Hg.

The system consists of two basic units—the gauge tube and the control circuit and meter. In operation, a voltage is introduced between the cathode and anode of the gauge. The resulting d.c. current between the two electrodes is proportionate to the amount of gas present, which in turn is the pressure. An easy-to-read triple scale provides direct-reading indication of pressures throughout the entire range of the gauge.

A constant magnetic field confines the residual gases to ensure proper measurement. A special ring anode design produces a more concentrated ion-discharge beam, which assures a cleaner tube and more accurate readings over a longer period of time. Both cathode and anode can be quickly and easily replaced when they become contaminated.

Dielectric Heating-3

Some further details of the uses to which dielectric heating can be put are given in this data sheet, being continued from data sheet No. 11.

The Woodworking Industry

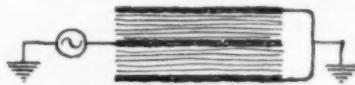
A most important development in recent years in the woodworking industry has been the introduction of synthetic resin adhesives of the thermosetting type for the bonding of wooden components. Setting of these resin adhesives proceeds at a rate largely determined by temperature. For instance, urea formaldehyde sets as follows :

TEMPERATURE	SETTING TIME
65°F	3 hours
80°F	1 hour
150°F	3 minutes
190°F	1 minute

The resultant bonded joint is equally satisfactory in each case. Most of the power supplied when dielectric heating is used is absorbed by the resin, the heat thus being concentrated where required.

Plywood

With dielectric heating consuming power only during the heating cycle, plywood can be produced with considerable savings in heating times and costs.



For example, in a press holding 100 3-ply $\frac{1}{2}$ " thick assemblies, the resin glue is set in 20-30 minutes, depending upon the dryness of the wood.

Curved Laminated Sections

Curved laminated sections are being increasingly used in contemporary furniture, and with dielectric heating rapid production can be achieved using

wooden shaping blocks in single daylight presses. An alternative method of providing heat by conduction from heated metal strips is much slower as the total section thickness rises above 0.05 inch.

*Furniture Assembly*

Because of the savings in glueing processes already instanced, dielectric heating is being extensively used in the furniture trade. It leads also to reductions in labour and floor space, with the elimination of assembly jigs. The heating equipment can be placed directly in the production line, cutting handling to a minimum.

Blockboard

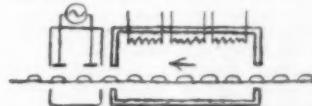
Blockboard, having large areas of glue line, provides an excellent use for dielectric heating, which gives considerable savings in time and labour.

Other Resin-bonded Products

Dielectric heating is also used in the manufacture of other resin-bonded or impregnated products such as grinding wheels, fabrics, felts, etc.

Foodstuffs

Increased use is being made of dielectric heating in many food processes; these include defreezing and melting, sterilisation and disinfection, drying of break-



fast cereals, dog biscuits, etc., and similar applications. Some cooking processes, such as bread baking, are technically possible, but dielectric heating gives an 'unbrown' product. In the biscuit trade, however, dielectric heating is combined with conventional baking to produce normal biscuits in $\frac{1}{2}$ to $\frac{1}{3}$ the usual baking time.

The examples given here cover only a part of the field open to dielectric heating.

For further information, get in touch with your Electricity Board or write direct to the Electrical Development Association, 2 Savoy Hill, London, W.C.2. Telephone: TEMple Bar 9434.

Excellent reference books on electricity and productivity (8/6 each, or 9/- post free) are available—"Induction and Dielectric Heating" is an example.

E.D.A. also have available on free loan in the United Kingdom a series of films on the industrial uses of electricity. Ask for a catalogue.

NEW PLANT

Fully automatic forging machine

The HILL ACME CO. has engineered and now has in successful field operation high-speed, fully automatic forging machines for large production operations. The design of these machines does not limit the number of passes or length of stock to be used. Pieces longer than 36 in. are supported by a walking beam through the various passes.

HILL ACME automatic forging machines are built in capacities from 1½-5 in. Production rates up to 60 forged pieces per minute, depending upon size of the machine, can be maintained regardless of the number of die positions required.

A 2-in. HILL ACME automatic forging machine with an induction heater produces ½ in. and ¾ in. mine roof bolts, in lengths from 12-72 in., at the rate of 45 pieces/min. in sustained operation. Bars are loaded into the feeding rack where an index feed, chain driven, positions them for proper spacing through the induction furnace. As the bar ends are heated they are delivered, at the proper timing cycle, to the forging machine by a roller chain feed where they are gauged for length, picked up by fingers and passed progressively through the dies. Finished forgings are discharged from the back of the machine by means of a separately driven conveyor, arranged for both right- and left-hand discharge.

Clean hardening small components

One of the equipments that attracted attention on the stand of Wild-Barfield Electric Furnaces Ltd., at a recent international machine tool exhibition held in London, was a small, sealed, quench slipper furnace (fig. 1).

The development of the sealed quench type of equipment is normally associated with the full-scale production of medium- and large-size components, but the furnace shown has been designed specifically for those who require to clean harden small components, such as miniature bearing parts, parts of watches and instruments and the like.

The furnace, rated at 4 kW., is a self-contained unit with built-in automatic temperature control and quench tank with immersion heater, thermostat and motor-driven agitator. Atmosphere control equipment is separate.

In construction, the furnace comprises a framework of angles that is extended downwards to form a stand of convenient working height, and laterally to form a support for the quench tank and control cubicle. Mild-steel sheet panels enclose the stand. The furnace chamber contains grooved refractories holding heating elements of nickel chromium alloy; the element bricks are backed by suitable insulation which is arranged to form a restricted vestibule at each end of the heating chamber. A rectangular retort of heat-resisting material having a cross-section 5 in. wide by 3 in. high is positioned in the chamber. The retort is extended through the vestibule at the entry end of the chamber and terminates in a hinged flap door through which work is charged. At the exit end, the retort is formed with a vertical duct which forms a quench chute into the quench tank.

A small slipper 4 in. in width and 6 in. long slides in the retort. It is provided with a long handle and hinged so that when pushed forward to the quench chute it tilts and precipitates work into the quench.

The quench tank forms an integral part of the furnace and is provided with a perforated plate extending its full width and length, positioned some 12 in. above the bottom. Beneath the plate are arranged an immersion

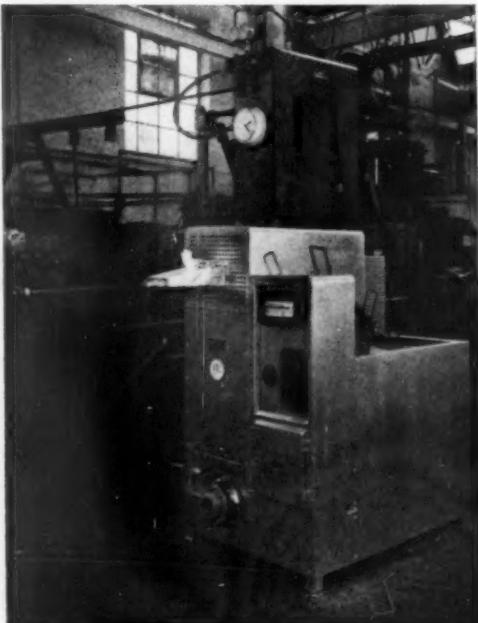
heater, thermostat and motor-driven agitator to keep the quenchant uniformly at a temperature at 60°C. Angle runners fitted into the quench tank act as guides for a catch basket, of which two are normally supplied. The baskets are provided with side rollers to fit the guides referred to and, upon withdrawal from the quench tank, are positioned upon a draining tray built over the quench.

Temperature control is effected by an automatic controller built into a cubicle on the front of the furnace. The cubicle houses also a dial-type thermometer indicating quenchant temperature, and a time switch with seven-day selective device and time switch case. Necessary pilot lights are also incorporated in the control panel. Switchgear, comprising a suitable relay and control circuit fuses, is readily accessible by the removal of a panel in the control cubicle. To safeguard the furnace in the event of accidental overheating, a fusible pattern excess temperature cut-out is provided.

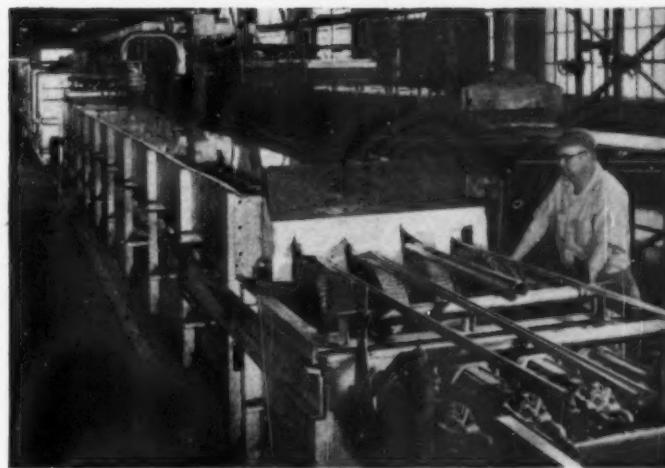
In operation, the slipper handle is fully extended to bring the slipper hearth beneath the open hinged flap door of the retort extension and work is inserted. The flap door is closed and the slipper handle—which is suitably marked—is pushed forward to position the slipper in the heating zone. After soaking at the required temperature, work is precipitated into the quench by moving the slipper handle fully forward.

For the purposes of atmosphere control, a panel is provided according to requirements. In the illustration, which features an equipment being employed for clean hardening parts of miniature bearings, a simple mixing panel for raw town's gas and ammonia was supplied.

1 Wild-Barfield quench slipper furnace



View of a continuous bright-annealing furnace installed at the Steel & Tubes Division of Republic Steel Corporation. It is capable of producing a high-quality finish on welded stainless-steel tubing without polishing for many applications. In this photo processed tubing is seen leaving the cooling chamber. The furnace eliminates the high cost of polishing and reduces ordinarily required pickling operations



Bright annealing stainless steel

A CONTINUOUS bright-annealing furnace capable of retaining the surface qualities of the original flat-rolled steel finish on welded stainless-steel tubing is in service at the Steel and Tubes Division of Republic Steel Corporation in the U.S.A.

Believed to be the largest furnace of its kind in the stainless tube industry, it can handle sizes from $\frac{1}{4}$ in. through 4 in. o.d. and maintains a high-quality finish without polishing for many applications. As a result, it can eliminate the high cost of polishing and, at the same time, eliminate about two-thirds of the usual pickling operations. The pickling still required is for cleaning purposes rather than for scale removal.

It has a rate capacity of 1,000 lb. h. at a maximum temperature of 1,150°C. The furnace proper consists of four high-temperature alloy-steel muffle tubes extending through a gas-fired furnace and connecting with tubular, water-cooled chambers. Alloy wire-mesh chain belts extending through these carry the work through heating and cooling chambers which cover an area 78 ft. long.

Operated by one man, it has power-driven feed and discharge conveyors, for handling the work to and from the furnace. The conveyors, along with the mesh belts carrying the work through the furnace, have adjustable speeds which permit variation of the traverse speed to suit the work being processed. These speeds vary from 1 to 6 ft. min.

The bright-annealed tubes have dense smooth surfaces similar to the original cold-rolled surface of the flat-rolled stainless steel and offer consider-

able sales appeal over a pickled or frosted finish for some applications. In addition, the resulting dense, smooth surface enhances the resistance to corrosion.

Until recently bright annealing of stainless tubing had been conducted only on a limited scale, and the method differed greatly from the bright annealing described here. Abrasion and scratching of the work, particularly on heavier stainless tubing, often resulted from the work being drawn or pushed through a muffle-type furnace with a water-cooled distribution chamber charged with dissociated ammonia atmosphere to secure the bright finish.

Classified Advertisements

FIFTEEN WORDS 7s. 6d. (minimum charge) and 4d. per word thereafter. Box number 2s. 6d. including postage of replies. Situations Wanted 2d. per word.

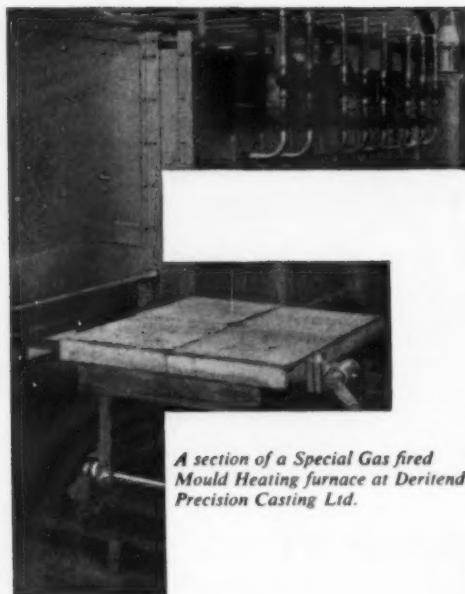
Replies addressed to Box Numbers are to be sent, clearly marked, to Metal Treatment and Drop Forging, John Adam House, John Adam Street, London, W.C.2.

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REQUIRED URGENTLY. Secondhand Massey, preferred drop hammer—10 cwt. capacity, also trimming press. Box RE 131, METAL TREATMENT AND DROP FORGING.

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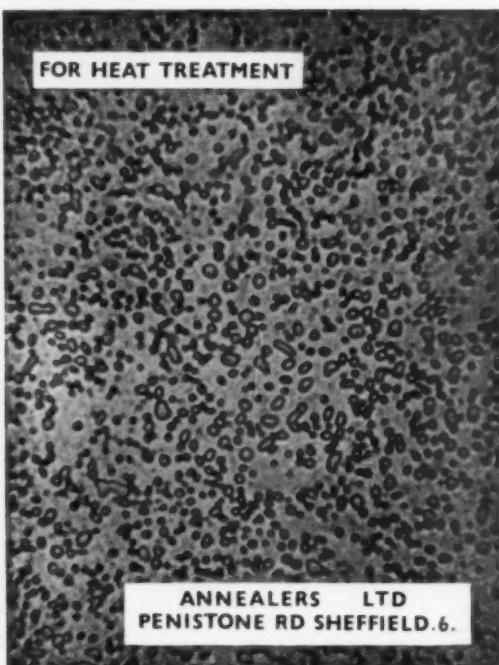
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